PETROGRAPHIC AND DIAGENETIC INVESTIGATION OF HABIB RAHI LIMESTONE, SULAIMAN BASIN, NORTH WAZIRISTAN, KP, PAKISTAN

Fawad Ahmed

01-262191-004

Department of Earth and Environmental Sciences

Bahria University, Islamabad

2021

PETROGRAPHIC AND DIAGENETIC INVESTIGATION OF HABIB RAHI LIMESTONE, SULAIMAN BASIN, NORTH WAZIRISTAN, KP, PAKISTAN

Fawad Ahmed

01-262191-004

A thesis submitted to Bahria University, Islamabad in partial fulfillment of the requirement for the degree of (MS in Geology)

Department of Earth and Environmental Sciences

Bahria University, Islamabad

2021

APPROVAL OF EXAMINATION

Scholar's Name: "FAWAD AHMED"

Registration No: "62417"

Programmed of Study: MS in Geology

Thesis Title: Petrographic and Diagenetic Investigation of Habib Rahi Limestone, Sulaiman Basin, North Waziristan, KP, Pakistan

It is to certify that the above scholar's thesis has been completed to my satisfaction and, to my belief, its standard is appropriate for submission for examination. I have also conducted a plagiarism test of this thesis using HEC prescribed software and found

Similarity index 16% that is within the permissible limit set by the HEC for the MS degree thesis. I have also found the thesis in a format recognized by the BU for the MS thesis.

Principal Supervisor's Signature: ____________________

Date:

Name: Prof. Dr. Mohammad Zafar

AUTHOR'S DECLARATION

I, "FAWAD AHMED" hereby state that my MS thesis titled **"Petrographic and Diagenetic Investigation of Habib Rahi Limestone, Sulaiman Basin, North Waziristan, KP, Pakistan"** is my own work and has not been submitted previously by me for taking any degree from this university "BAHRIA UNIVERSITY ISLAMABAD"or anywhere else in the country/world. At any time if my statement is found to be incorrect even after my graduation, the University has the right to withdraw/cancel my MS degree.

Name of scholar: FAWAD AHMED

Date:

PLAGIARISM UNDERTAKING

I, solemnly declare that research work presented in the thesis titled **"Petrographic and Diagenetic Investigation of Habib Rahi Limestone, Sulaiman Basin, North Waziristan, KP, Pakistan"** is solely my research work with no significant contribution from any other person. Small contribution/help wherever taken has been duly acknowledged and that complete thesis has been written by me.

I understand the zero-tolerance policy of the HEC and Bahria University towards plagiarism. Therefore, I as an Author of the above-titled thesis declare that no portion of my thesis has been plagiarized and any material used as reference is properly referred/cited.

I undertake that if I am found guilty of any formal plagiarism in the above titled thesis even after awarding of MS degree, the university reserves the right to withdraw/revoke my MS degree and that HEC and the university have the right to publish my name on the HEC and the University has the right to publish my name on the HEC/University website on which names of scholars are placed who submitted plagiarized thesis.

Scholar / Author's Sign: _______________

Name of the Scholar: FAWAD AHMED

DEDICATION

“Dedicated to my beloved parents, teachers, and friends”.

ACKNOWLEDGEMENTS

First and foremost, praise and thanks to Almighty Allah for His blessings and guidance at every step of my life. In the compilation of this thesis, the effort of many people and deep emotions were involved which deserves to be acknowledged. I would like to pay special thanks and deep gratitude to my thesis supervisor Professor Dr. Mohammad Zafar, Department of Earth and Environmental Sciences, Bahria University Islamabad Campus and my co-supervisor Asst. Prof. Mr. Imran Ahmad, Department of Geology, Malakand University. I express my sincere thanks to Professor Dr. Said Akbar Khan, Head of Department, for providing me with all the necessary facilities for my research work. I take this privilege to express gratitude to all faculty members especially Professor Dr.Tahseenullah Khan and Asst. Prof. Mr. Mumtaz Ali Khan for their help and support.

I am very thankful to Mr. Syed Irfan Ullah Hashmi, Sr. Geologist, Oil & Gas Facilitation Unit, Energy and Power Khyber Pakhtunkhwa, for his countless help, support, and guidance, especially in the field work. I also place on record, my sense of gratitude to my fellows for their assistance, encouragement, and stimulating discussions. I thank all those people, who helped me directly or indirectly in this venture.

A special feeling of gratitude to my loving parents, I'm heartedly grateful for their patience, support, and prayers for my success throughout my research work andlife in general. I would like to thank my siblings and friends for their support.

ABSTRACT

The early Eocene Habib Rahi Limestone of the North Waziristan, Sulaiman Basin has been studied for microfacies analysis, depositional model, diagenesis, and reservoir potential.This study is mainly focused on investigating and assessing reservoir quality using depositional and diagenetic processes. The Formation is composed of medium to thick-bedded, hard, highly fossiliferous, fractured limestone with interbedded shale and marls. Five microfacies have been identified based on the relative estimated ratio of allochems constituents and micrite. These microfacies are Mudstone, Wackstone, Wack-Packstone, Packstone, and Peloidal Grainstone and comprises larger benthic forams such as Nummulites, Assilina, Alveolina, Milliolids, Lockhartia, Orbitolites, and green algae. Based on mineral composition, fossil assemblages, and micritic matrix, the depositional environment for the Habib Rahi Limestone is interpreted as proximal inner ramp to distal middle ramp environment. The diagenetic processes observed in this study include micritization, cementation, dissolution, neomorphism, pyritization, mechanical and chemical compaction, stylolitization, sparitization, fracturing, and veins. The depositional, diagenetic, and deformation processes are the controlling factors of the distribution of porosity and permeability. The primary reservoir characteristics of this formation are highly affected by diagenetic processes developing it into a productive reservoir. Fracture and dissolution are significant mechanisms that increased the reservoir potential of the Habib Rahi Limestone at both the microscopic and macroscopic levels. In the studied section, the visually estimated average micro porosities of the Habib Rahi Limestone range from 0.5 to 2.1%. Intergranular porosity, dissolution porosity, moldic porosity, and fracture porosity are among the recognized porosity types.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General Description

The Sulaiman Range is situated on the northwestern boundary of the Indian Plate and constitutes the middle part of the Indus basin also known as Sulaiman Basin (Sarwar and Dejong, 1979; Jaumé and Lillie, 1988). Sulaiman Range is one of the largest mountain ranges of Pakistan occupying a major portion of the Middle Indus Basin. Sulaiman (Middle Indus) Basin is the largest, oldest, and traditionally gas-producing region in Pakistan (Kadri, 1995). This range is an established gas-prone area with many discoveries such as Sui, Uch, Zin, Pirkoh, Loti, Kandhkot, Jandran, Qadir pur, & Savi Ragha (Kadri, 1995). Sulaiman (Middle Indus) Basin is composed of a thick sedimentary sequence ranging in age from the Upper Paleozoic to Recent (Shah, 1977, 2009). The Paleogene sequence of Sulaiman (Middle Indus) Basin acts as a good source and reservoir for hydrocarbon exploration (Kadri, 1995). Clastic, carbonate and mixed clastic-carbonate rocks represent the Paleogene succession (Shah, 1977, 2009).

The study area has diverse and unique geology and in the terms of regional geological setting, it is located in the northern apical part of Axial Belt or Sulaiman Range. From an exploration point of view, the area is virgin because no such type of activities has been done due to security risks. The study area is composed of carbonates rocks.

Carbonate rocks are a variety of sedimentary rocks which are mainly composed of carbonate minerals. The two major types are Limestone, which is composed of calcite or aragonite (different crystals forms of $CaCO_3$ and dolostone, which is composed of the mineral dolomite ($CaMg\ (CO_3)_2$). Carbonate rocks are made up of particles that are more than 50% carbonate minerals embedded in cement. The majority of carbonate rocks form as a result of the accumulation of bioclasts produced by calcareous organisms. As a result, carbonates rocks form in areas favorable to biological activity, such as shallow and warm waters with little to no siliciclastic input.

Carbonate depositional environments and petroleum reservoir characteristics can be predicted using microfacies analyses and diagenetic studies of carbonate rocks (Scholle and Scholle 2003; Flügel 2004). It is essential to understand the type, nature, and structure of the carbonate shelf to develop reservoir units for hydrocarbons exploration (Kenter et al., 2005; Santantonio et al., 2013; Ni et al., 2016). The fundamental texture, mineralogy, chemical composition, and reservoir potential of carbonate rocks are all influenced by digenesis (Swart, 2015).

Eocene rocks are widely deposited in Pakistan. The extension of these rocks from the northern Himalayas to the southern parts of Arabian Sea. The thickness of the Eocene succession extends from a few hundred meters (in the northern sub-basin) to approximately 4000 meters (Axial belt in the south). Carbonates have an impact on the lithology of Eocene age rocks in Pakistan (Kadri, 1995). On the other hand, marine sediments (carbonates & shales) and localized evaporites were discovered in northern sub-basins. The highest percentage of hydrocarbon is found in Eocene-age rocks (Kadri, 1995). Carbonate sequence of Eocene age i.e., Sui Main Limestone, Habib Rahi, Sakesar, and Chorgali Formation have proven hydrocarbon reservoirsin Pakistan (Kadri 1995). In this study, the Habib Rahi Limestone of Eocene age was targeted for microfacies analysis and diagenetic study.

1.1 Location and Accessibility of the study area

Administratively the study area is situated at Shinki Post along the road in North Waziristan Khyber Pakhtunkhwa Pakistan. The area is easily accessible through Bannu-Mirali Road. Geologically, the study area signifies the frontal part of the northern Sulaiman Range.

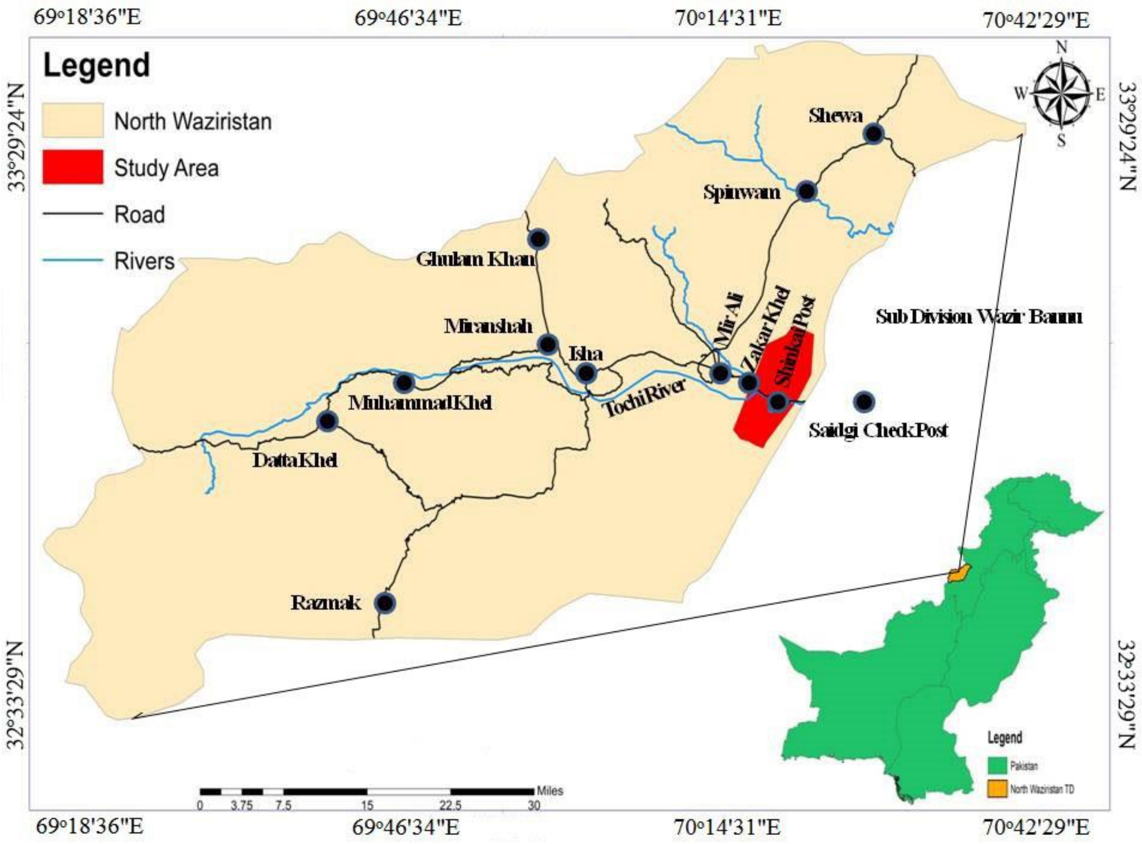


Figure 1.1 Location and accessibility map of the study area (ArcGIS).

The study area lies between Latitude 32º 56′ 07.83″ N to 32º 56′ 08.80″ N longitude 70º 22′ 26.01″ E 70º 22′ 22.41″ E and in the Sulaiman Basin, North Waziristan as shown in figure 1.1. The study area is located approximately 25km away from main Bannu city in the northwestern vicinity.

1.3 Literature Review

In1922, Stuart conducted the first geologic investigations in North Waziristan Agency, revealing the presence of Jurassic and Cretaceous rocks in the area for the first time. Fatmi and Khan (1966) designated the Kurram Group as the Mesozoic rock of the Orakzai Agency and Waziristan Agency. Hemphil and Kidwai (1973) put the rocks of Waziristan in chronological sequence for the first time, with excellent columnar sections and faunal descriptions of the region. Miessner et al. (1975) constructed a geological map of the Parachinar Quadrangle and designated the area's Mesozoic rocks as the Kurram Group. Beck et al. (1995,1996) made a regional sketch map of the area using Landsat pictures and indicated the existence of Mesozoic rocks. Ahmad et al., (2000) described the lithostratigraphy of Kurram group rocks along with Mirali-Miran Shah road, North

Waziristan Agency, NWFP Pakistan while Badshah (2000) explained the stratigraphy and tectonic evolution of the North-western Indian plate and Kabul Block. Shafique (2001) worked on the Spatial Biostratigraphy of NW Pakistan.

Microfacies, biostratigraphy, environments of deposition, and magneto-stratigraphy of Paleogene strata in various sections of Lower Indus Basin have been studied extensively (i.e., Iqbal, 1969; Friedman et al., 1992; Downing et al., 1993; Welcomme& Ginsburg, 1997; Afzal, 1996; Afzal et al., 1997; Welcomme et al., 2001; Warraich and Nishi, 2003); Métais et al., 2009; Rehman et al. (2017); Umar et al., 2020). Howard et al., described the Foraminiferal Biostratigraphy and microfacies of the Eocene Kirthar Formation, western Sulaiman Fold-Thrust Belt, Baluchistan, Pakistan.However, In the northern part of Sulaiman Range such information is missing for these rock units. Beck et al., (1995), Pivnik and Wells (1996) described Tethys closure in the Kohat and Potwar basins, as well as the Paleogene succession exposed there in Trans Indus Ranges. Roddaz et al., 2011; Zhaung et al., 2015, documented the movement history of the Indian plate along its western boundary using geochemical and geochronological data from rock units in the eastern range of Sulaiman and Southern Indus Basin. According to them, the suturing of India and Asia took place in the west about 50 million years ago.Umar et al., 2020) Microfacies, diagenesis and hydrocarbon potential of Eocene carbonate strata in Pakistan. The study conducted in this dissertation presents the Habib Rahi Limestone.

The Stratigraphic Committee derived the name Habib Rahi Formation from "Habib Rahi Limestone" of Tanish et al., (1959)and “Habib Rahi Member” of Meissner et al., (1968) and reported this formation in the Kohat quadrangle and Sulaiman Range. Initially, this formation was known Platy Limestone by La Touché (1893). The stratigraphic analysis of Habib Rahi Formation at North and South Waziristan of Sulaiman Ranges has done by Shah (1999). However, the detail microfacies and diagenetic study and reservoir capability of Habib Rahi Formation is still missing in the proposed study area. This study is carried out to collect information about detail microfacies and diagenetic investigation of Habib Rahi Formation to demarcate different microfacies, to interpret probable depositional model, to uncover all types of diagenetic alterations and to find out the impact of these modifications on the reservoir characterization of the proposed formation.

1.4 Problem Statement

The proposed study area is basically virgin in the context of exploration for hydrocarbons due to security risks. The equivalent stratigraphic units of the proposed area have been investigated for hydrocarbon exploration in Sulaiman range and now the oil industries are successfully producing hydrocarbons from Sulaiman Basin. Main theme of the proposed research project is to find out the reservoir potential in the carbonate succession of Eocene age, which act as proven reservoir in Sulaiman Basin. One mega research project under title "Source Rock Mapping and Investigation for Hydrocarbons Potentials in Federally Administrative Tribal Areas" by NCEG, University of Peshawar was carried out but was not successfully completed due to security risks.

1.5 Aims and objectives of the present study

Habib Rahi Limestone lies in favorable zone for petroleum system in a mature basin (Indus Basin). There is a strong need for detail study of Habib Rahi Limestone under the light of after mentioned aspects. The present study is carried out in order to create a conceptual depositional model of Habib Rahi Limestone and to know its diagenetic alteration processes after the deposition, involved in the modification of limestone of Habib Rahi Formation. For this detail field observations were recorded in the proposed study area and best exposure of Habib Rahi Limestone were marked. The main objectives of this research work include are:

1. To determine the microfacies of Habib Rahi Limestone.
2. To interpret depositional model for Habib Rahi Limestone.
3. To determine diagenetic types and establish a model of diagenetic events.
4. To determine the effects of diagenesis on porosity.

CHAPTER 2

REGIONAL TECTONIC SETTING AND STRATIGRAPHY

2.1 REGIONAL TECTONIC SETTING

Pakistan is a part of the Indian subcontinent, bounded to the south by the Indian Ocean and the north by the Himalayas (Figure 2.1), both of which are the result of geodynamic processes such as sea-floor spreading, continental drifting, and collision of platetectonics (Kazmi & Jan, 1997).

Initially, The Indus Basin sediments were deposited within the Paleo-Tethys, which is situated in central and eastern parts of Pakistan, along the northwestern passive continental margin of the Indo-Pak Subcontinent (Malkani, 2010). These sediments accumulated and were intensely folded during the orogenesis of the Himalayas, which formed the collision between Indian and Eurasian plates at around 55 Ma closing the Neo-Tethys Ocean (Powell, 1979; (Beck et al., 1995; Warraich and Nishi, 2003). The collision caused Himalaya to rise, as well as the formation of numerous folds and thrust belts which now flank the northern and western margins of the Indo-Pakistan plate (Figure 2.1). These belts are more than 100 Kilometers extend along a succession of lobes i.e., Salt, Sulaiman, and Kirthar Ranges, while in India where the width of the fold and thrust belt is less than 50 Kilometer (Figure 2.1). The northern boundary of the Indo-Pak plate remains convergent in Pakistan (i.e.,the Salt Range and Potwar Plateau), whereas oblique collision with the Afghan Block formed the Sulaiman and Kirthar Ranges in a transpressional zone towards the northwest and west, respectively (Figure 2.1) (Stonely, 1974; Powell, 1979; Kazmi and Rana, 1982). Different thrust systems are responsible for the development of various tectonostratigraphic zones of Pakistan. Shah (2009) divided these zones which includes; Indus Basin (includes Kohat-Potwar province, and Sulaiman-Kirthar province), Axial Belt (includes Southern sector from Arabian Sea and Northern sector to Hazara area), Baluchistan Basin (includes Chagai-Raskoh province and Makran Accretionary province), Himalayan Tectonostratigraphic Basin, Kohistan Island Arc and Karakoram-Hindukush Tectonostratigraphic Basin.

The Indus Basin has situated in the central and eastern parts of Pakistan. The Indus basin is divided into three sections: the Upper Indus basin (Kohat and Potwar), the Middle (Sulaiman) Indus basin, and the Lower Indus basin (Kirthar). Axial Belt separates the Indus basin from the Baluchistan Basin (Malkani, 2010). The Sulaiman basin is one of the largest Basins covering approximately 170,000 Km^2 area (Malkani, 2010). The Sargodha Highs and Pezu uplift border the Sulaiman Basin to the north, Khairpur-Jacobabad highs (Sukkur Rift) to the south, Indian Shield rocks to the east, and the Axial Belt to the west (Kadri, 1995; Malkani, 2010). From west to east, the major tectonic zones of the Sulaiman Basin include the arc-shaped Sulaiman Fold Belts, the arc-shaped Sulaiman Foredeep, and a monoclonal zone called Punjab Monocline (Kadri, 1995; Malkani, 2010).

The study area is located in North Waziristan, which is a part of Sulaiman Basin. Waziristan forms the northwest part of the Indus Basin and is geographically situated at the northern edge of Axial belt and Sulaiman Range. The substantial fold and thrust system are bounded on the west by a zone of Ophiolites, the Chaman Fault, and the rocks of Katawaz basin (Khurshid et al., 1992).

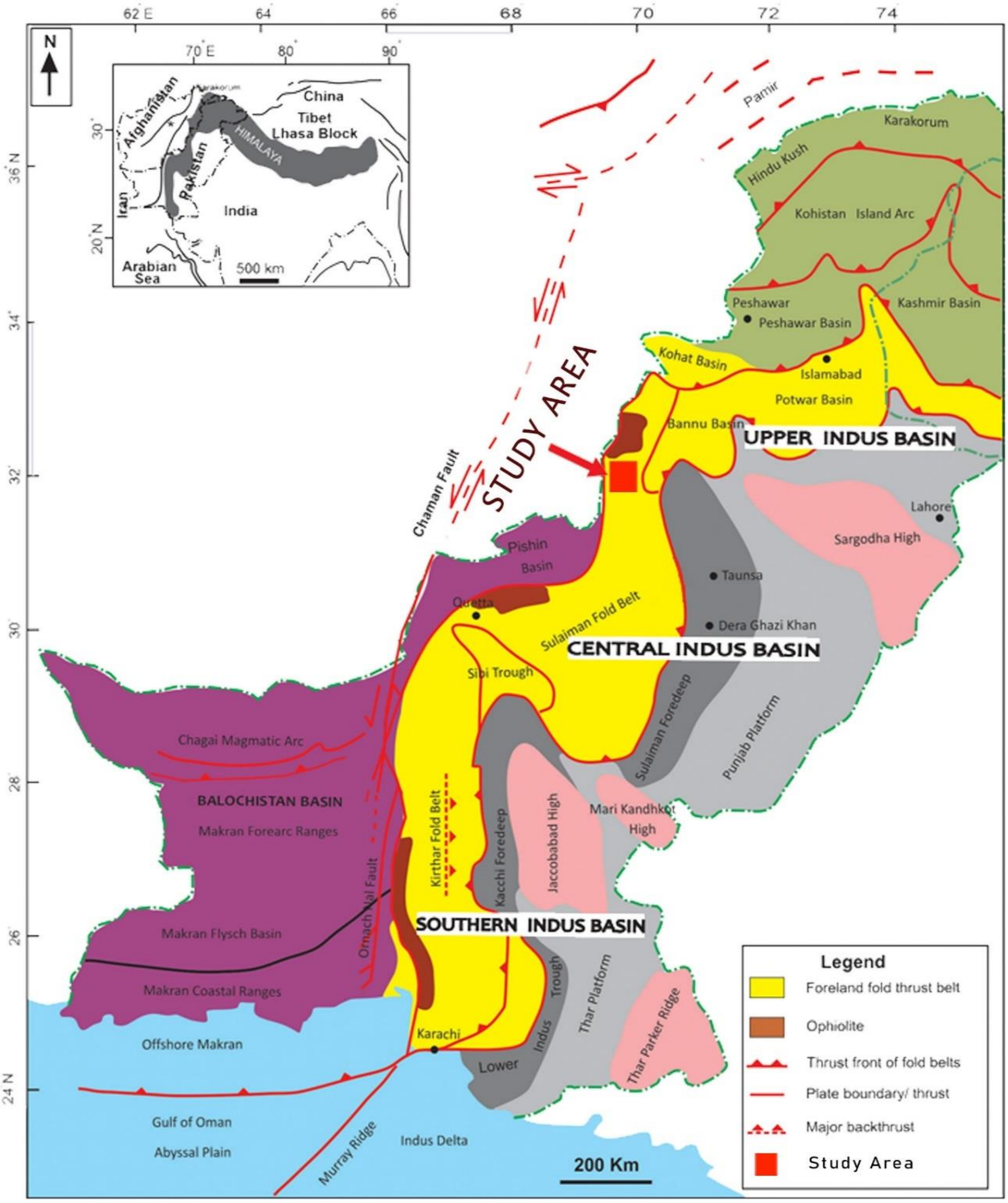


Figure 2.1: Tectonic framework and sedimentary basins of Pakistan (Farah et al.,1984; Kadri, 1995). Inset shows the entire Himalayan and Sulaiman-Kirthar ranges (after Najman,2005). Red colour rectangular inset shows the study area.

2.2 Stratigraphy of the Sulaiman Basin

The Sulaiman Basin is characterised by a thick sequence of sedimentary rock ranging from the Triassic period to recent (Shah, 2009). The Wulgai Formation is the oldest rocks exposed in this basin, which is of the Triassic age (Raza et al, 1989). Stratigraphy of Sulaiman Basin is documented by many researchers such as (Raza et al., 2001; Shah, 2002; Kazmi and Abbasi 2008; Shah, 2009; and Malkani, 2010).

The Wulgai Formation contains variegated shales with limestones and siltstone interbeds. The Spingwar Formation of the Jurassic age comprised of micritic limestones, shales, and marl beds in the basal part while sandstones and subordinate limestone, shales, and marls in the upper part, covers the Wulgai Formation. The Spingwar Formation has the conformable upper contact with the Loralai Formation having limestone, shale, and marls interbeds. The Chilton Limestone overlies the Loralai Formation. The Chilton Limestone is comprised of variegated limestone having conformable upper contact with the cretaceous age deposits named as Sembar Formation.

The Sembar Formation contains black silty shales with interbeds of black siltstone and nodular argillaceous and glauconitic limestone beds (William, 1959). The Sembar Formation has conformable upper contact with the Goru Formation. The lithology present in this formation is interbedded limestone, shale, and siltstone. The Parh Limestone containing limestone, calcareous shale, and marl intercalations (Khan, 2012) covers the Goru Formation. The Parh Limestone has conformable upper contact with the Mughal Kot Formation of the Late Cretaceous. The Mughal Kot Formation comprises calcareous mudstone and calcareous shale with intercalation of quartzose sandstone and argillaceous limestones (Hemphill and Kidwai, 1973). The Mughal Kot Formation has conformable upper contact with the Fort Munro Formation which contains limestones with marls intercalations. The Pab Formation having sandstones, marls, and argillaceous limestone are interbedded. The Pab Formation is covered by the Ranikot Formation of early to middle Paleocene comprising of variegated sandstone, shale, and limestone (Kadri, 1995). The Ranikot Formation has conformable upper contact with the Rakhi Gaj Formation of the Late Paleocene age.

Rakhi Gaj Formation consists of shales with subordinated sandstones and few limestone bands. The Dungan Formation containing nodular limestone with subordinate shales, marls, sandstones, and limestone conglomerates. The Dungan Formation has conformable upper contact with the Shaheed Ghat Formation of early Eocene. This Formation is comprised of variegated clays with subordinate beds of limestone, marl, and fossiliferous marly clays. The Drug Formation covers the Shaheed Ghat Formation and contains pebbly nodular limestone interbedded with the variegated color shales. The Drug Formation has conformable upper contact with the Toi Formation. The Toi Formation comprises sandstone, siltstone, conglomerates, silty claystone, and shales. The Toi Formation is covered by the Ghazij Shales which contains variegated shales, siltstones, conglomerates, and silty claystone (Malkani 2010). The Ghazij Shales is overlain by the Habib Rahi Limestone comprised of hard limestone, interbedded marls, and shales. The Habib Rahi Limestone has conformable upper contact with the Domanda Formation having claystone and sandstone. The Domanda Formation is covered by the Pirkoh Formation which containing limestone and claystone (Shah, 2009).

The Pirkoh Formation has conformable upper contact with the Darzinda Formation of late Eocene age. The Darzinda Formation consists of clays with marl interbeds at places. The Darzinda Formation has conformable upper contact with the Chitarwata Formation of Oligocene age. Chitarwata Formation comprises of siltstone, sandstone and shale (Hemphill and Kidwai, 1973). The Chitarwata Formation has conformable upper contact with Miocene age deposits of the Vihowa Formation which include shales, sandstones and conglomerates. The Vihowa Formation is covered by the Litra Formation containing sandstones, subordinate shales, and conglomerates. The Litra Formation has conformable upper contact with the Chaudhwan Formation of Pliocene age comprised of alternating shales/mudstones, sandstones, and conglomerates. The Chaudhwan Formation is covered by the Dada Formation of Pleistocene age deposits which include conglomerates, shales, and sandstones. The Dada Formation is covered by the surficial deposits of recent age (Malkani, 2012).

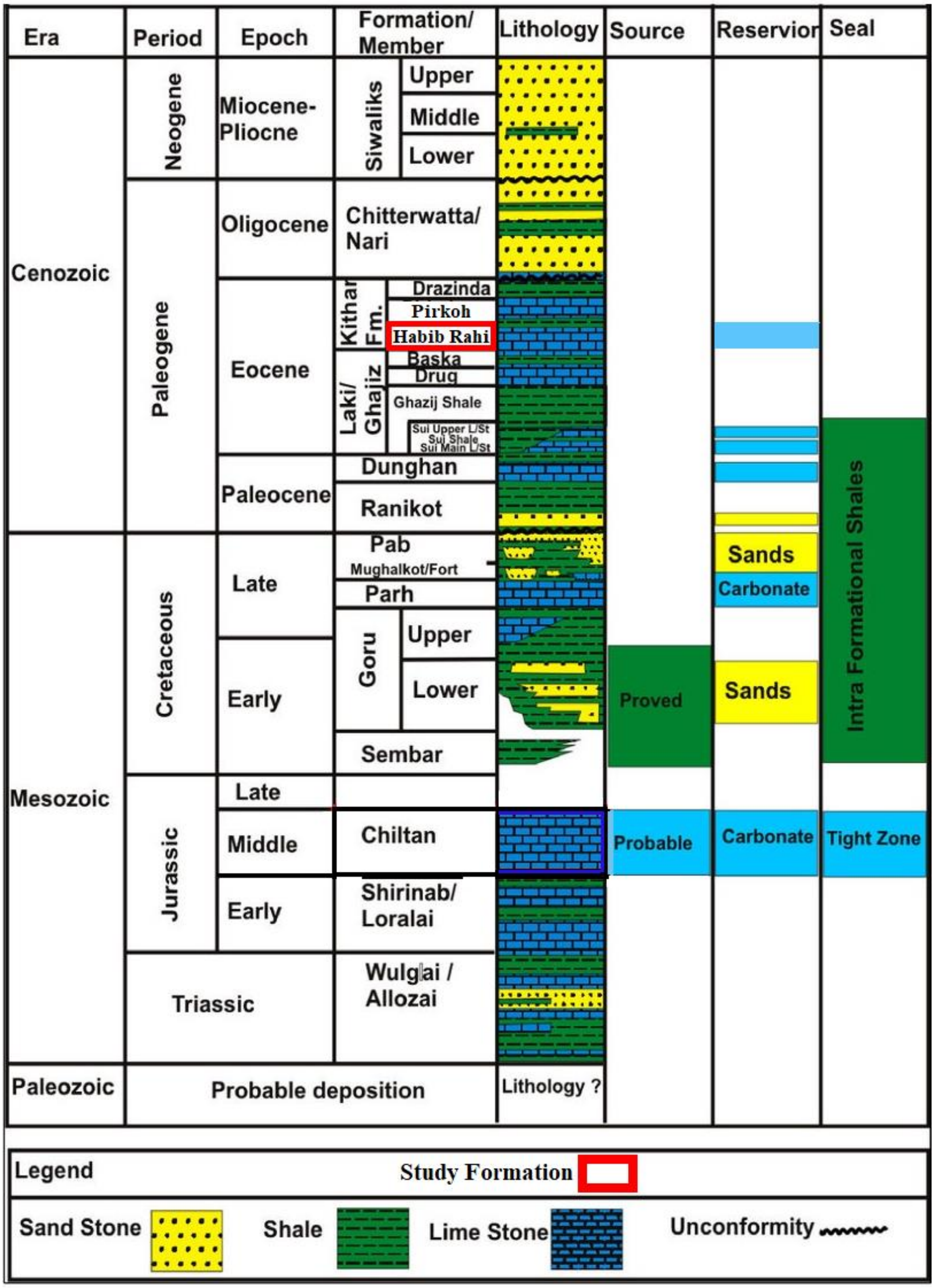


Figure 2.2 Showing the generalized stratigraphy of Sulaiman Fold Belt (Kadri 1995).

CHAPTER 3

METHODOLOGY AND FIELD OBSERVATION

3.1 Methodology

The methodology comprises different field techniques and laboratory techniques i.e., Field work, thin section and microscopy for petrographic study, and scanning electron microscopy.

To achieve the mentioned objectives the following methodology was adopted:

1. Field Work
2. Laboratory Work

3.1.1 Field Work:

The geological field work was conducted for the study of Habib Rahi Formation along the road in Shinki Post section, Sulaiman Range, (Sulaiman) Basin, North Waziristan, Khyber Pakhtunkhwa Pakistan to investigate the petrographic study, depositional environment, diagenetic processes and also to study their reservoir behavior in the study area. A total of 27 rock samples were collected from Habib Rahi Limestone in Shinki Post, among them, 22 samples were selected as representative samples. Samples were selected at a specific interval and on the base of lithological and textural variations. A measuring tape was used to determine the exposed thickness of the formation. The total measured thickness of the Habib Rahi Limestone was about 55m at Shinki Post, North Waziristan section. Field features were also observed.

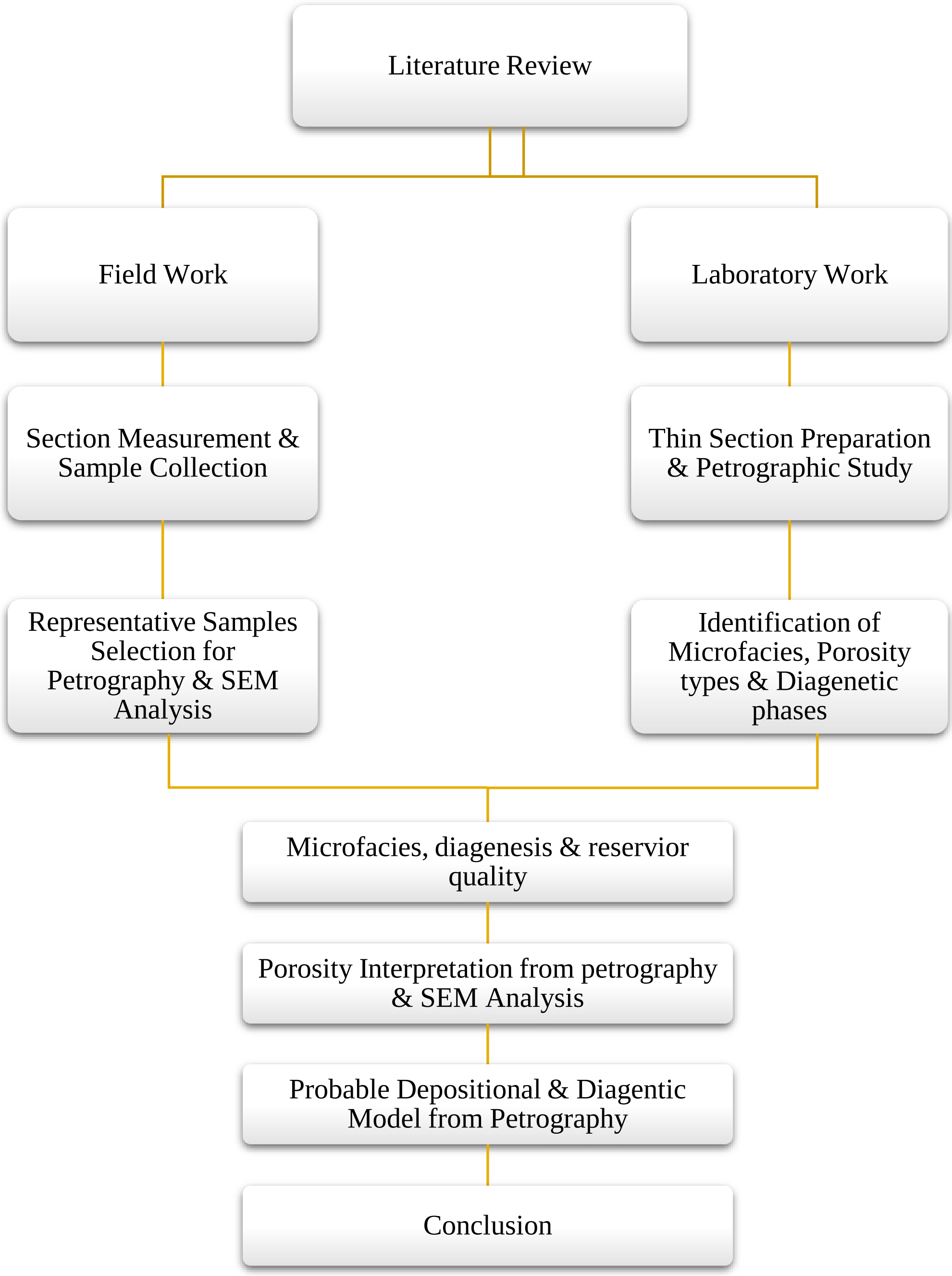


Figure 3.1 Showing flow chart for the methodology as adopted in the research work.

3.1.1.1 Field Description of Eocene Strata in the Study Area

The Sulaiman Basin is comprised of Triassic to Recent rocks. However, this study is focused on the Eocene Habib Rahi Limestone of Shinki Post Section, Sulaiman Range. In the studied section, Ghazij Formation marks conformable lower contact of Habib Rahi Limestone (Fig.3.3). Ghazij Formation is composed of the variegated color of shales i.e., red shales, black shales, grey shales, brown shales, with thin layers of limestone, sandstone, siltstones, and silty claystone. Habib Rahi Limestone is comprised of cream to grey color hard argillaceous limestone with intercalation of marls. The total thickness of the formation is 56 meters. Habib Rahi Limestone is thick to thin-bedded (at an average of 1m to 9m). The lower portion contains thin-medium bedded limestone with interbedded marls (Fig.3.4). Striation is present in this part of the limestone. The middle part of the Habib Rahi Limestone contains medium to thick-bedded limestone and minor beds of marl. At some places, fractured limestone, and nodularity are also observed. At some portions, limestone and marl contain some macro fossils which can be seen with the naked eye. Alveolina and Nummulites can be observed in both upper and lower units of the study area, while Assilina is rare.The upper part of the formation is comprised of hard limestone having cream and grey in color. Calcite veins are present in this part of the formation. Grey marl bed can be observed at the top of the formation. Both on the weathered and fresh surface the color of the limestone is cream and grey while the marl is of brown and grey color. In the middle part of the formation macro fossils were also observed. In the studied section, the upper contact of Habib RahiLimestone is unconformable with the sandstone of Chitarwata Formation (Fig.3.3). ChitarwataFormation is composed of siltstone, sandstone, conglomerates, and shale.

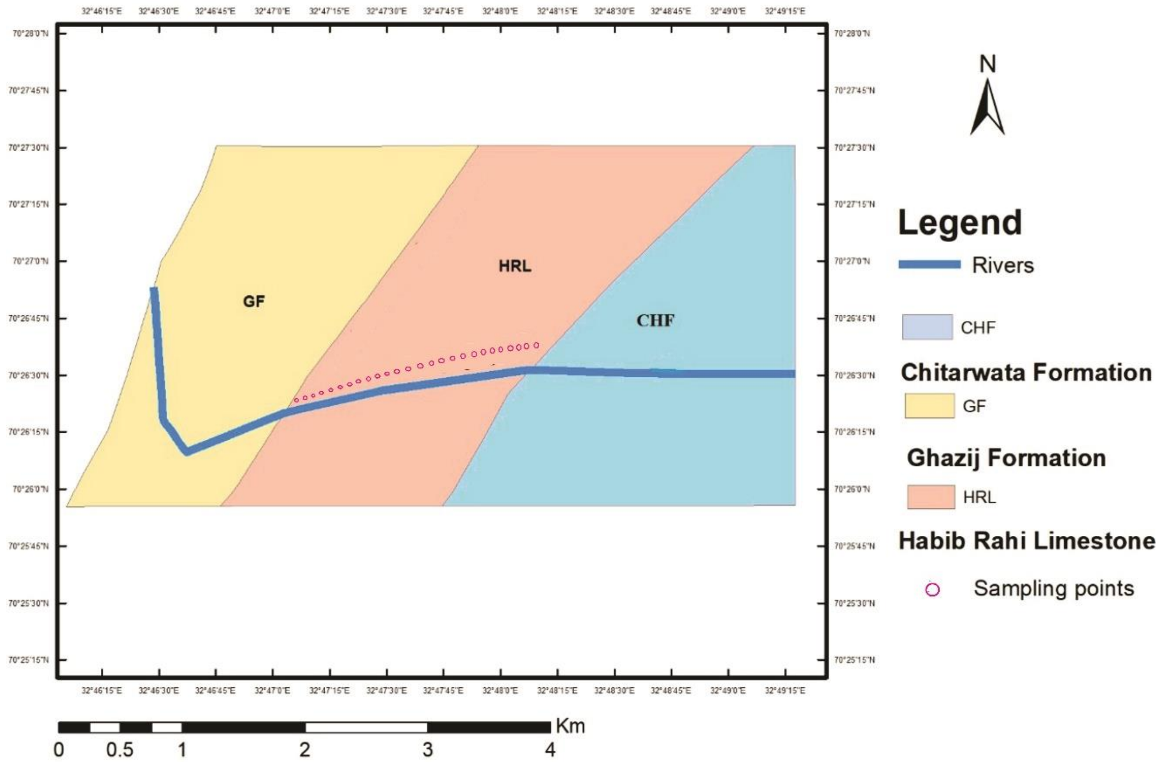


Figure 3.2 Sampling location map of the study area (modified after Badshah, 2000).

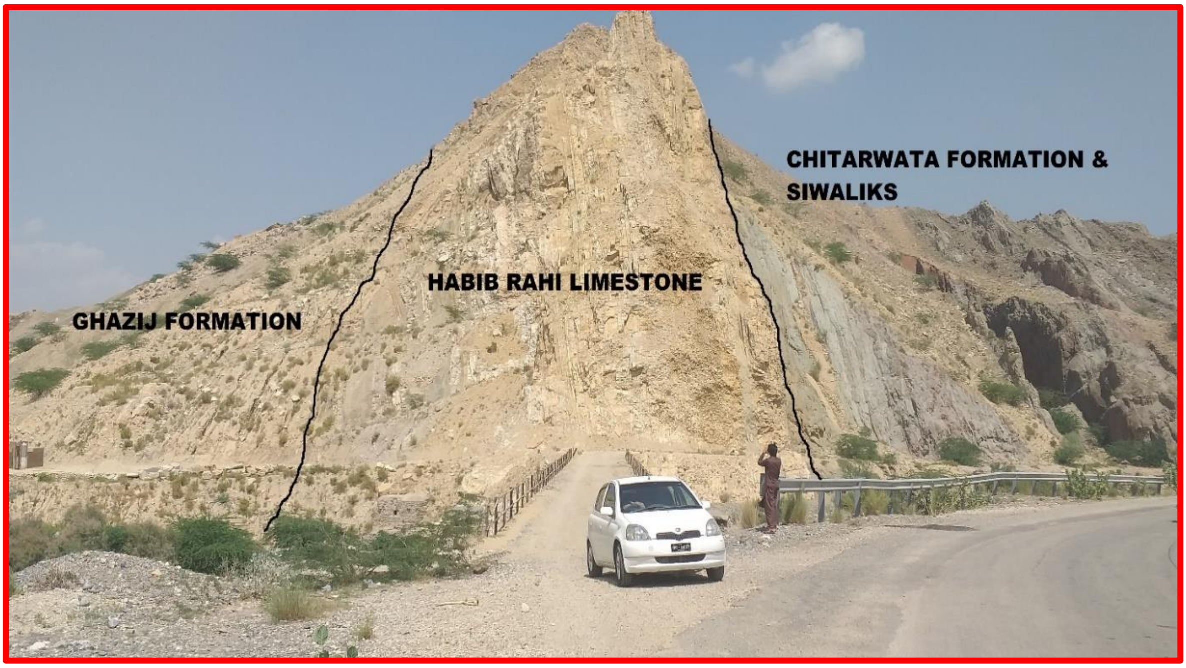


Figure 3.3 Lower conformable and upper unconformable contacts of Habib Rahi Limestone.

Figure 3.4 A field photograph of Habib Rahi Limestone with shale intercalations.

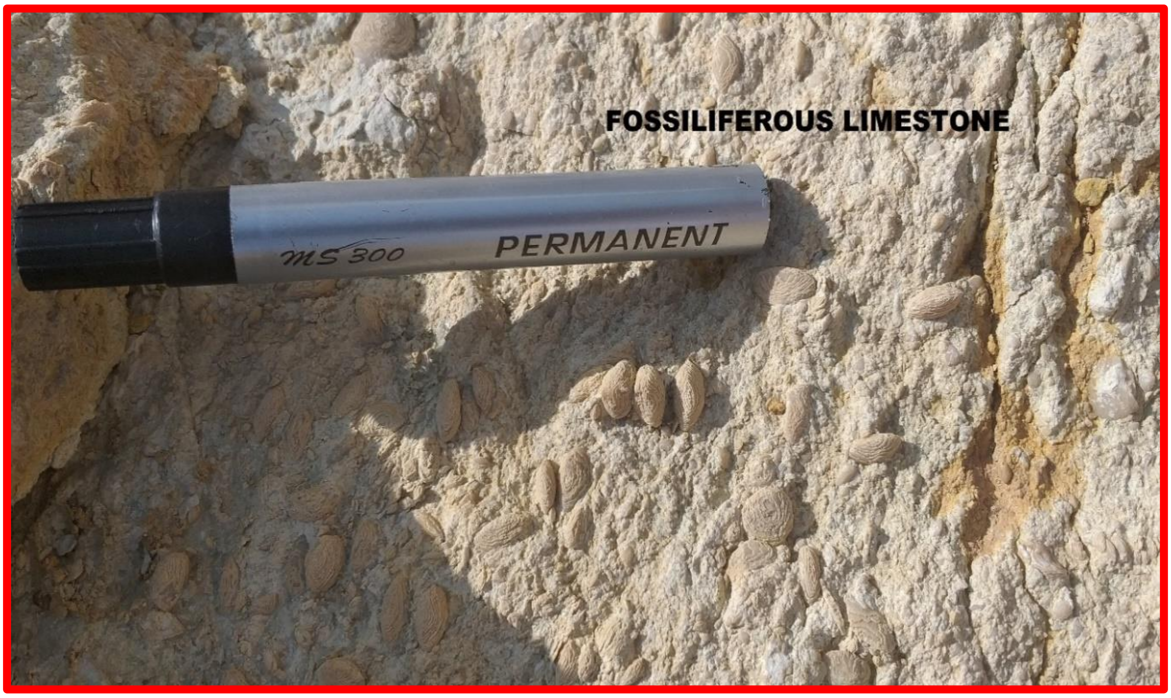


Figure 3.5 Photograph of Habib Rahi Limestone having abundant benthic foraminifers fossils.

Figure 3.6 Photograph showing calcite veins in the Habib Rahi Limestone.

Figure 3.7 Photograph showing fractures in the Habib Rahi Limestone.

Figure 3.8 Photograph showing nodule and fractures in Habib Rahi Limestone.

3.1.2 Laboratory Work

A total of 27 samples of Carbonate (Limestone) out of 22 representatively samples were cut into thin sectionsfor petrographic study in the thin section laboratory of (NCEG), University of Peshawar. Then the thin sections were studied microscopically using conventional plane polarized microscope. The photomicrographs of these thin sections are captured through DP-21 camera attached to Leica DM750P plane polarized microscope. The petrographic analysis of these thin sections was performed in the Petrographic Laboratory of Bahria University Islamabad campus.

The allochems, matrix, and cement percentages were used to perform microfacies analysis, which was then classified using the Dunham classification scheme (1962). These petrographic data were compared to Standard Microfacies (SMF) types of Flugel (2004) and Wilson (1975), to interpret the depositional environments of the carbonate units.

3.1.2.1 Scanning Electron Microscopy (SEM)

SEM analysis produces images of analyzed samples by scanning them with a directed electron beam. Before analyzing the sample with an SEM instrument, the sample is gold coated with the help of a BIO-RAD SC502 Sputter. Various signals are produced as a result of electron interactions with atoms in a sample, which contain information about the sample's composition and topography. These signals are then detected by a detector and displayed in the form of an image. The resulting image then represents variation in atomic number due to compositional changes, which in turn provides information about different mineral phases within the analyzed sample (Dilks and Garham, 1985).

The working principle of SEM includes an electron gun with a tungsten filament that emits an electron beam. This beam is focused on the sample specimen by passing it through a series of electromagnetic lenses. As a result, some of the electrons that strike the sample reflect (backscattered electrons), while others refract (un-reflected) as secondary electrons, which are then collected by the Scintillator (sensor) when the SEM is in normal mode to produce an image of the sample. Only reflected electrons are collected by a detector (standard type collector called Scintillator- photomultiplier) when the SEM is in reflected mode (when a negative potential is applied to the shield/gauze, which blocks low energy electrons). A vacuum pump is also present in the SEM to remove air from the electron column.

SEM images have high magnification, they can reveal details about micro porosity and crystal texture. For this dissertation, three samples are analyzed using SEM, and their SEM photomicrographs are captured using SemAfore Digitizer Software, Version 5.1. (JEOL, 1993-2008).

CHAPTER 4

PETROGRAPHY

4.1 Introduction

In 1969 Nicolas Steno for the first time used the term “Facies”. In 1838 a Swiss geologist AmanzGressly introduced the geological usage of the term “Facies” with its implication in the modern world, which indicates the sum of the lithological and paleontological aspects of a stratigraphic unit. Brown (1943) and Cuvillier (1952) refined the term as the sum of all the sedimentological and paleontological criteria defining a rock in a thin section. Wilson (1975) refined the concept of Cuvillier's (1952) depositional interpretation of facies by defining the SMF (24 standard microfacies types and 8 facies belt) and utilising Dunham's (1962) and Folk's (1962) classification combined with (Flügel, 1982) paleontological observation. As a result, the term microfacies can be defined as a systematic sum of sedimentological and paleontological data sets extracted from thin sections, polished slabs,peels, or rock samples (Flügel, 2004). Depositional studies (based on microfacies) of Habib Rahi Limestone are relied on detailed geological field work, petrographic analysis, bed strata/layer characteristic features, organic/inorganic allochems types, and textural variations are used to recognize and understand conditions required for deposition of each microfacies. Each microfacies and is classified according to Dunham classification scheme (1962). This chapter aims to study the petrography, developing different microfacies, and sort out the feasible depositional model for Habib Rahi Limestone exposed in Shinki Post, Sulaiman Basin, North Waziristan.

Dunham’s classification (1962) is more helpful for classifying hand samples and utilizes the percentage of mud in the rock as a proxy to energy regime and sediment supply. An increase in the amount of mud in the matrix may indicate either a loss in energy or an increase in the availability of fine-grained particles. It is a textural scheme determined essentially by whether the larger grains and sand-sized are in contact with one another or replacement cement. Grains supported rocks are classified as Grainstone, which has no mud in its voids, and Packstone which have mud in the interstices Wackstone is classified as a mud-supported rock in which larger grains occupy more than 10% of the volume, and mudstone is defined as rocks that include more than 90% matrix. The conclusion is that grain-supported rocks developed from sediments in well-washed environments, which are high in energy, but other forms of rock with more mud indicate gradually calm conditions (Davis, 1983). Boundstones are biogenic rocks that have been bonded together by encrusting organisms (i.e., “reef-like” fabrics).

It should be observed that the nature of the grains involved is important in determining whether or not a grain-supported texture is produced. Certain biogenic particles, such as bivalve shells or branching corals, or algae, may comprise only 30%-40% of the volume but still produced a grain-supported texture. By contrast, spherical grains would have to comprise about two-third of the volume to produce a grain-supported texture (Davis, 1983).

Depositional Texture Recognizable					Depositional Texture Not Recognizable (Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Original Components Not Bound Together During Deposition				Original components were bound together during deposition, as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interslices.	
Contains mud (particles of clay and fine silt size, less than 20 microns)			Grain-supported		
Mud-supported		Grain-supported			
Less than 10 percent grains	More than 10 percent grains	More than 10 percent mud	Less than 10 percent mud		
Mudstone	**Wackestone**	**Packstone**	**Grainstone**	**Boundstone**	**Crystalline Carbonate**

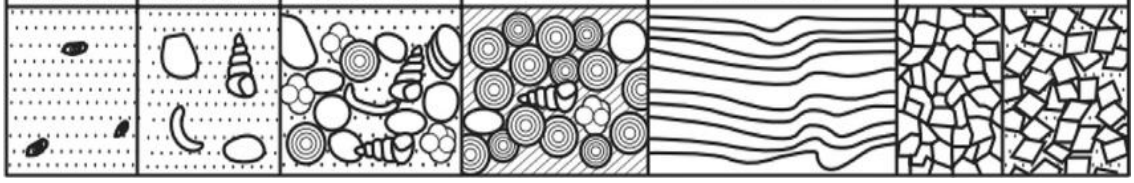


Table 4.1 Showing Dunham classification scheme (1962).

4.2 Methodology

Paleoenvironments analysis of Habib Rahi Limestone is based on extensive field work and petrographic study.Habib Rahi Limestone consists of limestone with sub-ordinates marl and shale units. Allochems types, bedding characteristics, and textural distinction are used to interpret the depositional environments of each microfacies (Ali et al., 2013). Total 27 samples were collected from Limestone units in the study area, while shale and marl units remain un-sampled. The samples were collected based on fossil contents, sedimentary structures, lithology, variation in color, and texture. 22 thin sections were prepared for detailed petrographic analysis, which is classified/named according to Dunham classification scheme (1962). For the interpretation of depositional environments, each microfacies is correlated with Ramp Microfacies (RMF) of Wilson (1975) and Flügel (2004).

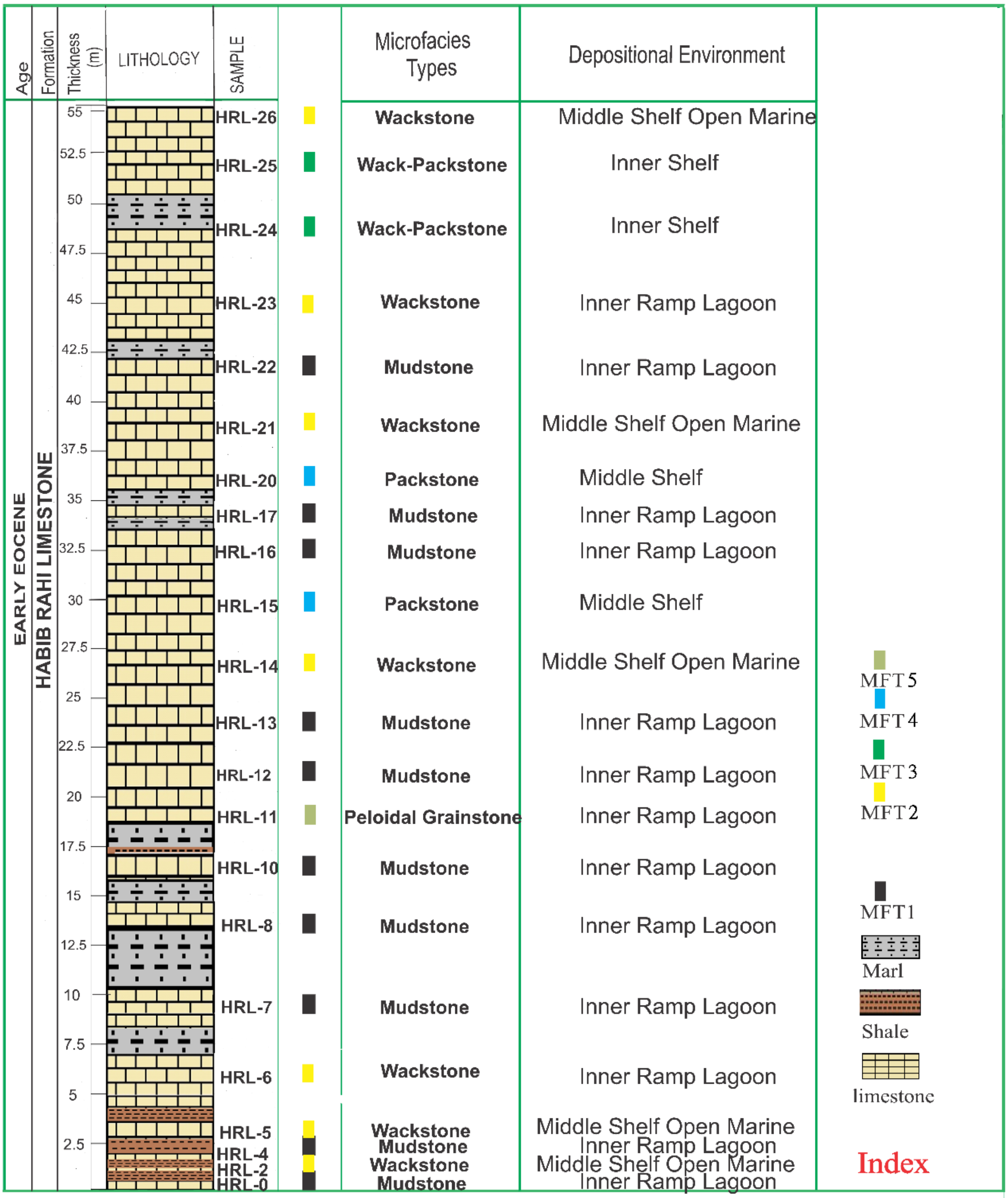


Figure 4.1 Litholog showing varying lithology, sample locations, microfacies types and environments of deposition of Habib Rahi Limestone.

Table 4.2 Table showing the petrographic description of allochems and matrix percentage of Habib Rahi Limestone, Shinki Post, North Waziristan.

THINSECTION NO	***ALLOCHEM PERCENTAGE (%)***												***Peloidal G.stone***	**M:G**	**Name as per Dunham Classification (1962)**
	Nummulities	***Assilina***	***Milliolids***	***Alveolina***	***Algae***	***Lockhartia***	***Brachiopods***	***Briozones***	***Echinoderms***	***Recrystalized Bivalves***	***Planktonic Foraminifera***	***Biserial Foraminifera***			
HRL #26	×	10%	1%	×	×	×	×	×	×	×	×	×	×	89:11	Wackstone
HRL #25	1%	40%	×	×	×	×	×	×	×	×	×	×	×	59:41	Assilina Wack-Packstone
HRL #24	2%	×	×	35%	×	1%	×	×	×	×	×	×	×	62:38	Alveolina Wack-Packstone
HRL #23	7%	2%	3%	10%	×	×	×	×	×	×	×	×	×	80:22	Wackstone
HRL #22	2%	×	×	×	×	×	×	×	×	×	×	×	×	98:2	Mudstone
HRL #21	87%	×	×	×	×	×	×	×	×	×	×	×	×	13:87	Nummulitic Packstone
HRL #20	4%	×	×	3%	×	×	×	×	×	×	×	×	×	93:7	Mudstone
HRL #17	×	×	×	×	×	×	×	×	×	×	×	×	×	100:0	Mudstone
HRL #16	×	×	×	×	×	×	×	×	×	×	×	×	×	100:0	Mudstone
HRL #15	×	73%	1%	×	×	×	×	×	×	×	×	×	×	26:74	Assilina Packstone
HRL #14	4%	×	2%	15%	×	×	×	×	×	×	×	×	×	79:21	Wackstone
HRL #13	4%	×	×	1%	×	×	×	×	×	×	×	×	×	95:5	Mudstone
HRL #12	4%	×	×	1%	×	×	×	×	×	×	×	×	×	95:5	Mudstone
HRL #11	×	×	×	×	×	×	×	×	×	×	×	×	90%	10:90	Peloidal Grainstone
HRL #10	×	×	×	×	×	×	×	×	×	×	×	×	×	100:0	Mudstone
HRL #08	2%	×	×	4%	2%	×	×	×	×	×	×	×	×	92:8	Mudstone

HRL #07	2%	×	×	6%	×	×	×	×	×	×	×	×	×	92:8	Mudstone
HRL #06	10%	×	×	1%	1%	5%	×	×	×	×	×	×	×	83:17	Wackstone
HRL #05	4%	×	3%	×	×	3%	2%	3%	3%	2%	×	×	×	80:20	Wackstone
HRL #04	×	×	×	×	×	×	×	×	×	×	×	×	×	100:0	Mudstone
HRL #02	×	×	2%	×	×	×	×	2%		×	6%	4%	×	86:14	Wackstone
HRL #00	×	×	×	×	×	×	×	×	×	×	×	×	×	98:2	Mudstone

4.3 Results

On the basis of petrographical analysis six microfacies have been identified in Habib Rahi Limestone such as;

1. Bioclastic Mudstone Microfacies (MFT-1)
2. Foraminiferal Wackstone Microfacies (MFT-2)
3. Wacke-Packstone Microfacies (MFT-3)
   a. Assilina Wacke-Packstone Sub-Microfacies (1A)
   b. Alveolina Wacke-Packstone Sub-Microfacies (1B)
4. Packstone Microfacies (MFT-4)
   a. Nummulitic Packstone Sub-Microfacies (1A)
   b. Assilina Packstone Sub-Microfacies (1B)
5. Peloidal Grainstone Microfacies (MFT-5)

4.3.1 Bioclastic Mudstone Microfacies (MFT-1)

Field Features

The Bioclastic Mudstone Microfacies is represented by thin section number HRL-0, 4, 7,8,10, 12, 13, 16, 17 20, and 22. This microfacies consists of cream and grey colour having thin to massive bedded, fractured, and highly fossiliferous limestone. In some places this microfacies contains minor nodular limestone having minor calcite veins.

Petrographic Descriptions

This microfacies is characterized by mudstone depositional texture. The petrographic description of this microfacies consists of micritic mud as a cement with few allochems.In some cases, micrite is re-crystalized to sparite. This microfacies consists of abundance amount of matrix. The average mud/matrix percentage is 94% while the skeletal allochems percentage is 6%. Under the microscopic observation this facie contains Alveolina, Nummulites, algae and broken bioclasts. The allochems percentage such as Nummulites 3%, Alveolina 2.5%, and algae .5%. In this facie fractures and veins are present which are filled by calcite.

Interpretation

The microfacies is characterised by lime mud, and a limited fauna, suggesting that it was deposited in a restricted environment on the inner shelf. This microfacies is associated with Wilson (1975) and Flugel (2004) RMF 19 (SMF-23) which is deposited in facies zone FZ-8, showing lagoonal setting. The depositional depth of Alveolina and Nummulites ranges from 20 to 130 meter. Deposition in very low energy environment is also indicated by very fine-grained siliciclasts and mud supported texture.

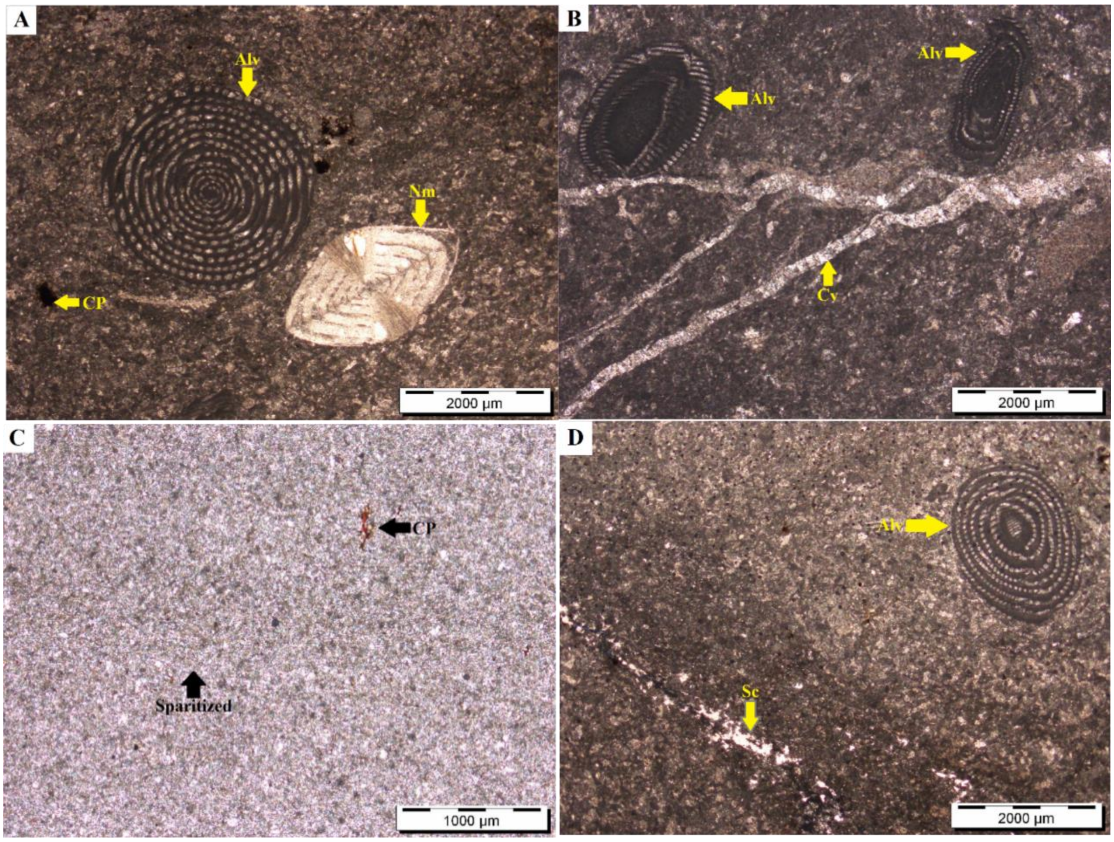


Figure 4.2: Photomicrographs showing the Bioclastic mudstone microfacies (MFT-1): The skeleton's allochems of microfacies including lager benthic foraminifers, i.e., Nummulites Nm (in a), Alveolina (Alv in a, b, and d). The crystal of pyrite is represented by CP in (a, c), calcite vein is denoted by Cv in (b),conversion of micritic matrix into micro spar in (c) and sparry calcite is represented by Sc in (d).

4.3.2 Foraminiferal Wackstone Microfacies (MFT-2)

Field Features

Foraminiferal Wackstone microfacies are represented by thin section number HRL-2, 5, 6, 7, 14, 23, and 26. At the outcrop this microfacies having cream colour of limestone. This microfacies consists of medium to coarse grain and thin to medium beds of limestone. This microfacies is highly fossiliferous. The limestone is nodular and fractured. These fractures are filled by the calcite crystals.

Petrographic Description

This microfacies is dominated by micritic matrix and skeletal allochems. The average micrite matrix proportion is 77 percent. Under the microscope, petrographic observation revealed that the skeletal allochems are primarily composed of larger benthonic foraminifera, with an abundance of fossils. The percentage of allochems in this microfacies is 23%. Benthonic foraminifera assemblage includes Nummulites,Sp 3%, Assilina,Sp 2.5%, Milliolid 2%, Lockhartia Sp4%, Briozones 2%, Brachiopods 2%, Recrystallized Bivalves 2%, Orbitolites2% and planktonic foraminifera 3.5%.
This microfacies shows that some parts of the rock under microscopic observations shows veins and fractures which are filled by calcite. Pyrite is also present.

Interpretation

The deposition of this microfacies represents moderate energy conditions and in the middle shelf as this facie contains benthic foraminifers, planktonic foraminifera indicate moderate energy condition which lies in the inner shelf. This microfacies is corelated with Ramp microfacies type RMF-20 (SMF-9) of Wilson 1975 and Flugel 2004. This microfacies is deposited within the facie zone FZ-7 in the open marine platform.

The association of milliolids and algae suggest that deposition took place in warmer shallow water depth (10-15m) (Heckel, 1972), rotaliids are mostly found at a depth of about 20 meters. Milliolids and Alveolina persist in a shallow inner shelf setting. The presence of Nummulites and Assilina further suggests that this microfacies deposition took place under FWWB (Racey, 1994).

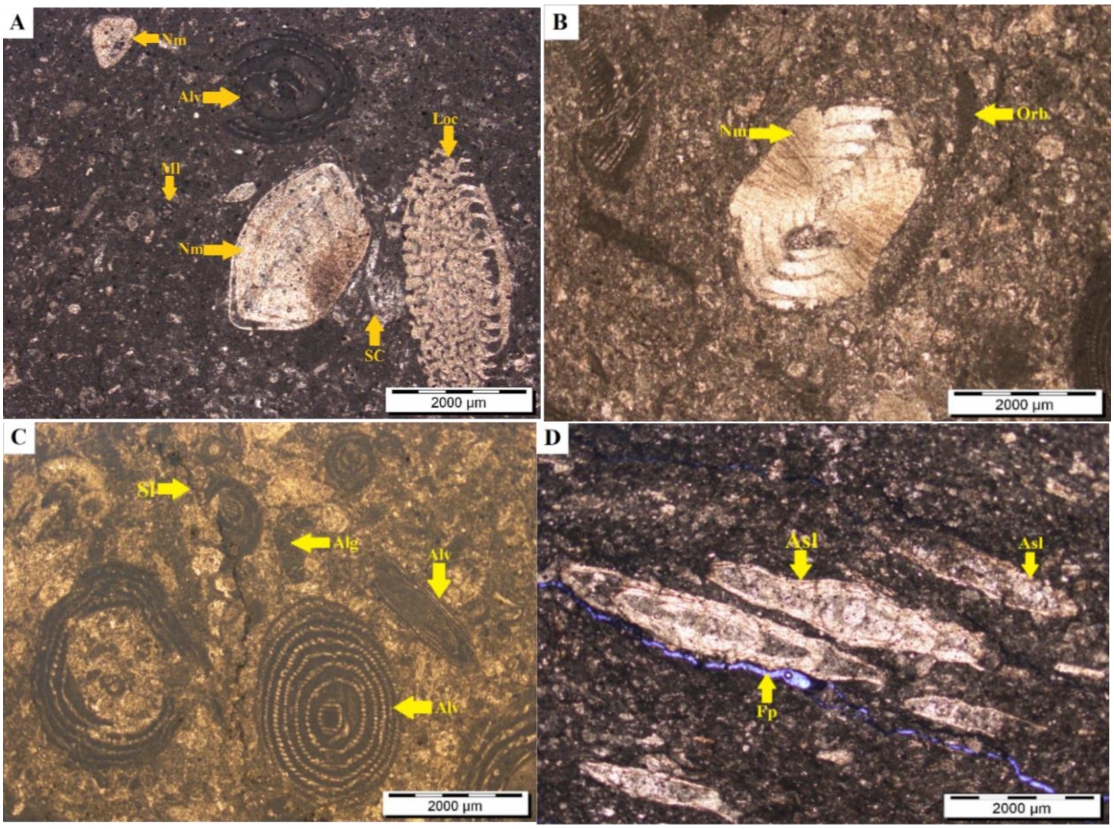


Figure 4.3: Photomicrograph showing Foraminiferal Wackstone (MFT-2): the allochems of such microfacies include larger foraminifers: Alveolina Alv in (a and c), Nummulites Nm (in a and b), Milliolids Ml in (a), Lockhartia Loc in (a), Orbitolites Orb (in b), Assilina sp Asl (in d), Planktonic foraminifera PF in (a), Broken bioclast Bb (in a) and Algae Alg (in c). Fracture porosity is represented by Fp (in d), and Stylolites Sl (in c).

4.3.3 Wacke-Packstone Microfacies (MFT-3)

The Wackstone Microfacies are divided into sub-microfacies;

a. Assilina Wacke-Packstone Sub-Microfacies (1A)
b. Alveolina Wacke-Packstone Sub-Microfacies (1B)

4.3.3.1 Assilina Wacke-Packstone Sub-Microfacies

Field Features

Assilina Wacke-Packstone Microfacies is the sub-microfacies of the Wacke-Packstone. This microfacies are represented by thin section number HRL-25. On the outcrop the colour of this microfacies is cream and grey. The Assilina Wacke-Packstone microfacies consists of minor nodules and having medium to thick bedded fossiliferous limestone.

Petrographic Description

Petrographic description of this microfacies under the petrographic observation shows abundant amount of allochems. The matrix percentage of this microfacies is of 59% while the percentage of skeletal allochems or grains are 41%. The skeletal allochems such as Assilina 40% and Nummulites are of 1%. Fractures and pyritization is also observed.

Interpretation

This microfacies is characterised by the presence of lime-mud with variety of larger benthonic foraminifers such as Assilina and Nummulites, according to which this microfacies is deposited in shallow, subtidal conditions on the distal inner shelf with no reworking. Such microfacies is correlated to SMF- 9 (RMF-20) of Wilson (1975) and Flugel (2004). Which is deposited in facie zone FZ-7.

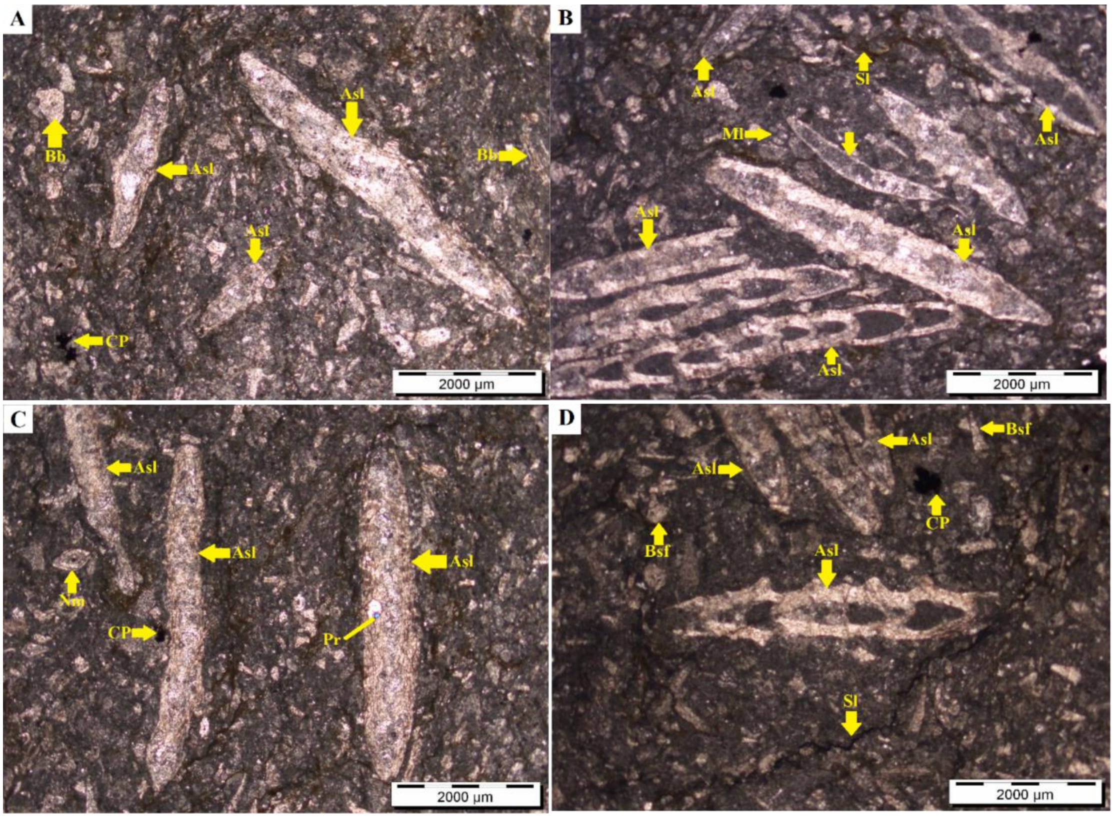


Figure 4.4: Photomicrographs indicating Assilina Wacke-Packstone (MFT-3): the allochems of this microfacies includes larger benthic foraminifera (LBF): Assilina sp Asl in (a, b, c, &d), Milliolids Ml in (b), Broken bioclast Bb in (a), and Broken shell fragments Bsf (in d). Crystalof pyrites is denoted by CP in (a, c, and d), Stylolitesare indicating by Sl (in b, d).

4.3.3.2 Alveolina Wacke-Packstone Sub-Microfacies

Field Features

The Alveolina Wacke-Packstone Microfacies is denoted by thin section number HRL-24. The limestones of this microfacies are pale cream in colour, and having fine to medium beds. The microfacies are highly fossiliferous and having fine to medium coarse grains limestones.

Petrographic Description

Wacke-Packstone depositional texture is characterized by this microfacies. Microscopically, this microfacies is characterized by larger benthic foraminifera. This facies contains abundant amount of Alveolina fossils. The allochems percentage of this microfacies is 38% while the matrix percentage is 62%. The allochems or grains such as Alveolina 35%, Nummulites 2% and Lockhartia 1%.

Interpretation

Generally, Alveolina may found in shallow inner shelf or lagoon (Henson, 1950). During the Eocene, Alveolina is found distributed on the back reef, fore reef and in shallow water (Ghose, 1977; Pautal. 1987), The sedimentological and paleontological evidences favor the deposition of these facies in the inner shelf environments with a depth less than 30m. The microfacies is corelated with SMF (standardmicrofacies type)–10 (RMF-20) of Wilson (1975) and Flugel (1982), which is deposited in facies zone FZ-7.

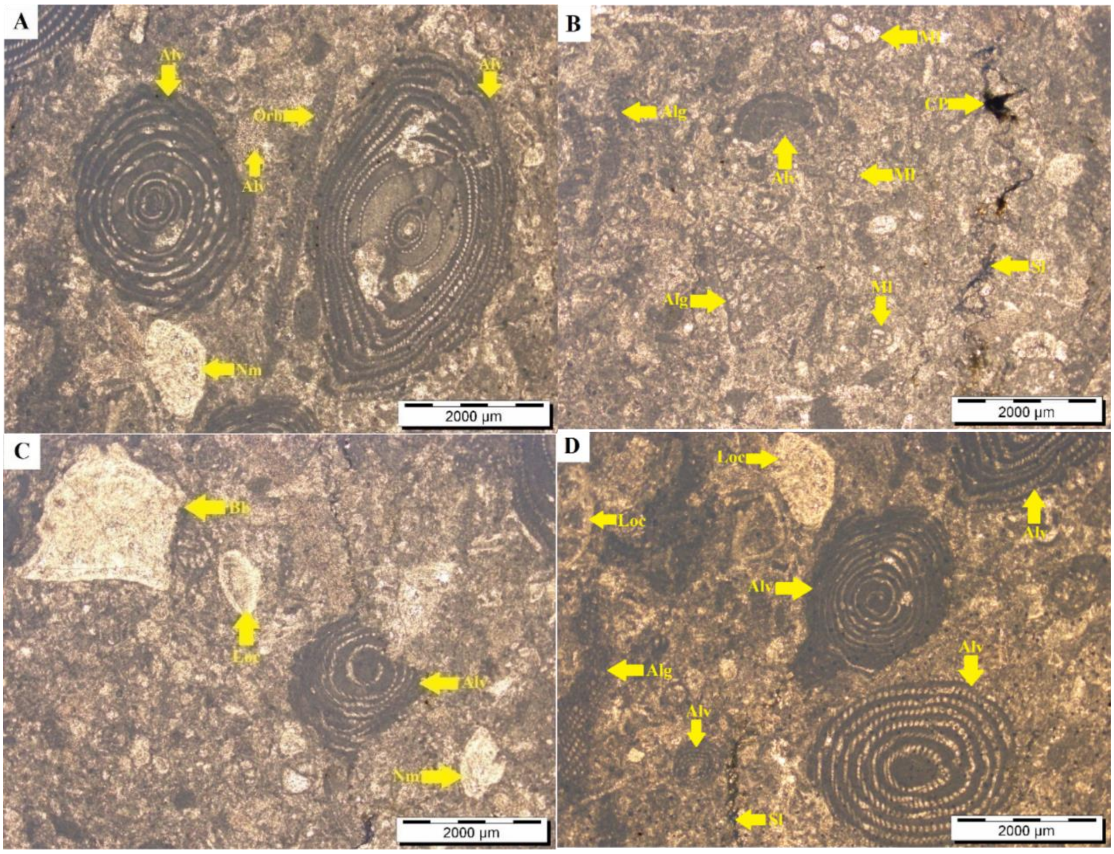


Figure 4.5: Photomicrographs showing Alveolina-Wacke-Packstone: the grains of this microfacies includes: Alveolina Sp, Alv in (a, c, d), Lockhartia Loc in (a, c, d), Nummulites Nm (in c), Orbitolites Orb (in a), Milliolids Ml in (b), and Algae Alg in (a, b, d). Stylolite is represented by Sl (in b, d) and Crystal of pyrite CP (in b).

4.3.4 Packstone Microfacies (MFT-4)

Packstone Microfacies are classified into sub-microfacies;

a. Nummulitic Packstone Sub-Microfacies (1A)

b. Assilina Packstone Sub-Microfacies (1B)

4.3.4.1 Nummulitic Packstone Sub-Microfacies

This microfacies is the sub microfacies of Packstone Microfacies which is represented by thin section number HRL-21. Nummulitic Packstone microfacies consists of cream colour. The limestone of this microfacies is highly fossiliferous. It contains medium to thick beds of limestone which are medium to coarse grains. Macro fossils are also present on the outcrop of this microfacies.

Petrographic Descriptions

This microfacies is characterized by Packstone depositional fabric. Petrographic description of this microfacies shows abundance of Nummulitic fossils. This facie is dominantly composed of allochems having percentage of 87% while the percentage of matrix is 13%. Benthic foraminifera such as Nummulites Sp are of 87%. Bioclasts of Nummulites are also present.

Interpretations

The nummulitic Packstone submicrofacies is primarily composed of Nummulites and micritic matrix. The nummulitic foraminifers are benthic organisms found at depths ranging from 20 to 130 meters (Reiss and Hottinger, 1984). Nummulites have been documented from all across the world, and they are most common in the middle ramp setting (Racey, 1994; Anketell and Mriheel 2000; Racey, 2001; Vaziri-Moghaddam et al., 2006; Adabi et al., 2008; Payros et al., 2010; Mehr and Adabi, 2014). However, the significant diversity of Nummulites sp. and the presence of a micritic matrix appear to indicate that the MFT-4 sub-microfacies are deposited in a lowenergy middle ramp setting.

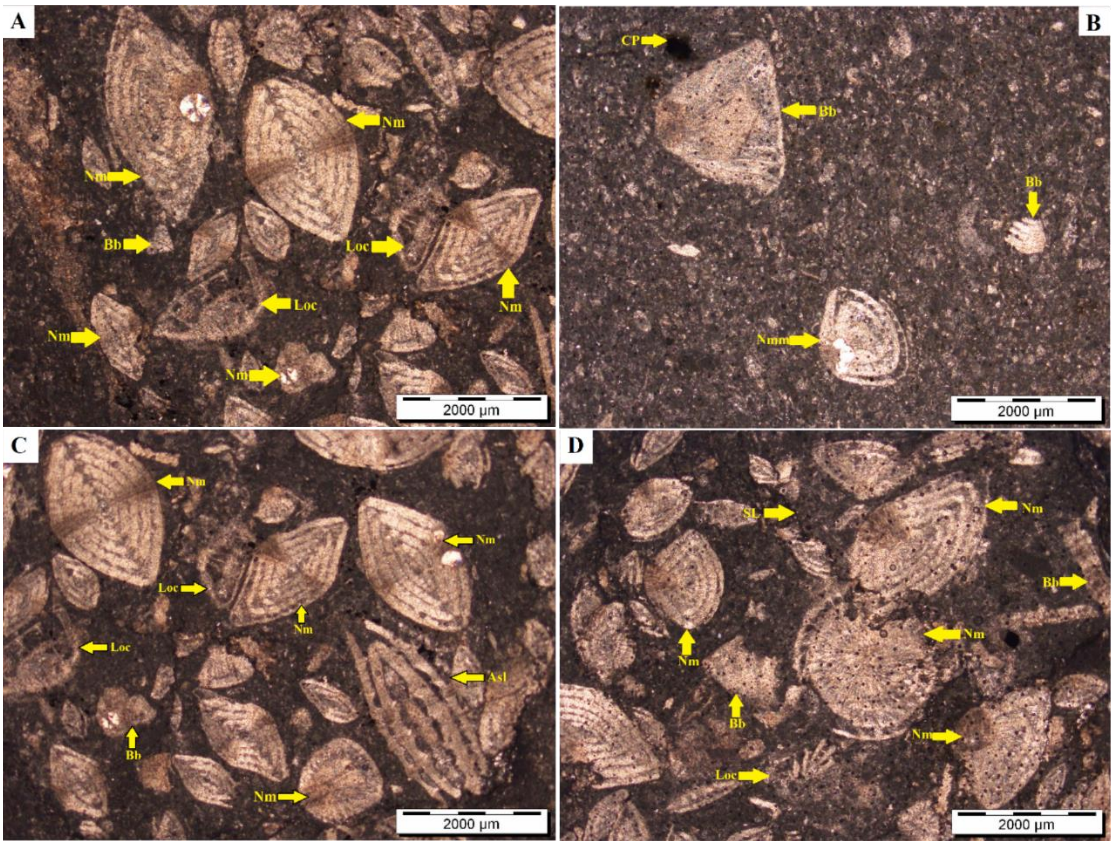


Figure 4.6: Photomicrographs showing Nummulitic Packstone (MFT-4): the skeletal grains of this microfacies includes LBF: Nummulites Sp, (in a, b, c, d), Lockhartia Loc (in a, c, d), Assilina Sp Asl (in c) and broken bioclast Bb (in a, b, c, d). Crystal of pyrite is represented by CP (in b) and stylolitesSl (in d).

4.3.4.2 Assilina Packstone Sub-Microfacies

Field Features

Assilina Packstone Sub-Microfacies is characterized by thin section number HRL-15. This microfacies is consists of yellowish cream colour. It comprises of medium to thick bedded limestone. This microfacies are less compacted and having macro fossils. The limestone of this microfacies is coarse grain and highly fossiliferous.

Petrographic Descriptions

This microfacies is also categorized by Packstone depositional texture. In petrographic study this microfacies show abundance of fossils. This facie contains allochems with percentage of 74% while matrix percentage is 26%. Embraced larger benthic foraminifera like Assilina 73%, and Milliolids 1%. Microscopically fractures are also present in this facie.

Interpretation

The microfossils like Assilina sp and Ranikotalia sp suggests relatively deeper, normal marine, quite condition for the deposition (Racey, 1994). Assilina lives at about 80m depth on the carbonate platform, except in restricted back-reef environments on the middle shelf (Geel, 2000). Milliolids live in a restricted lagoonal setting (Flugel, 2004). However, the Packstone are generally deposited in the inner shelf setting so this microfacies is correlated with the standard microfacies SMF-18 and RMF-13 of Wilson 1975 and Flugel 2004), which is deposited in the distal middle shelf environment.

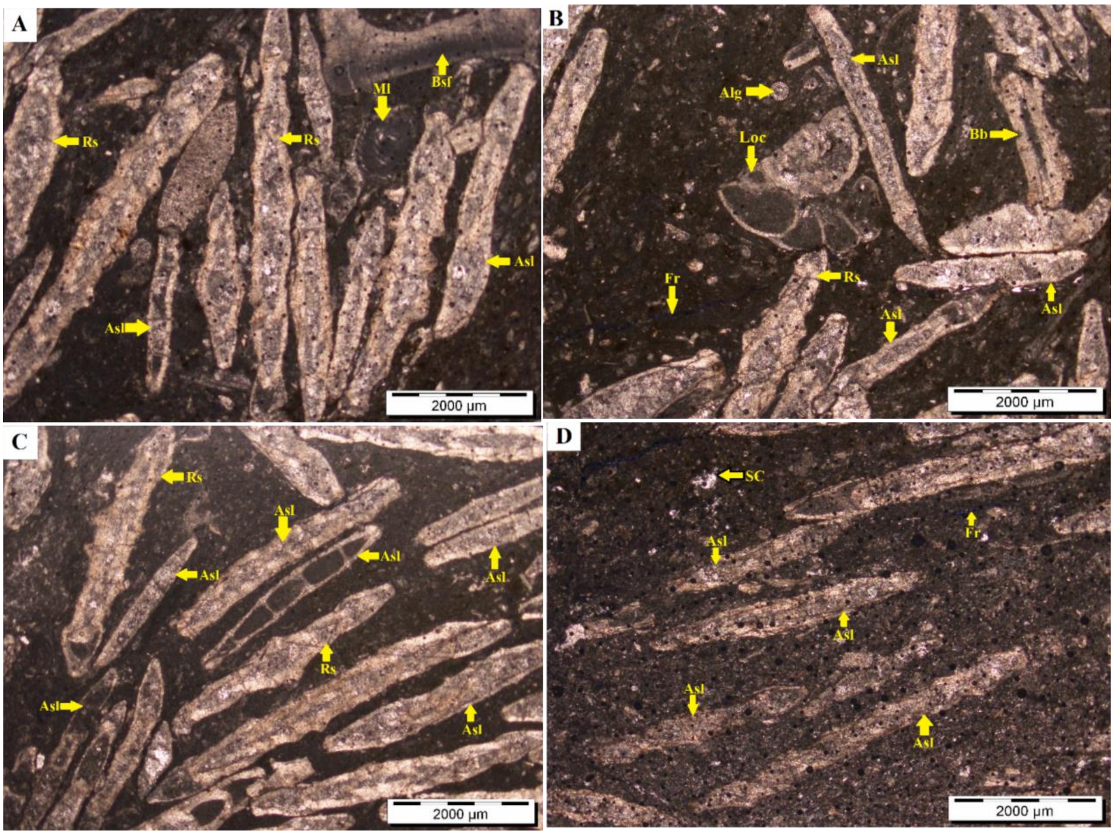


Figure 4.7: Photomicrographs showing Assilina Packstone (MFT-4): the allochems of this microfacies include: Assilina Sp Asl (in a, b, c, d), Ranikotalia Sp Rs (in a, c), Milliolids Ml (in a), Lockhartia Loc (in b), broken bioclast Bb (in a, b) and algae Alg (in b). Sparrycalcite is denoted by SC in (d), while Fracture porosity Fp (in d).

4.3.5 Peloidal Grainstone Microfacies (MFT-5)

Field Features

Peloidal Grainstone Microfacies are represented by thin section number HRL-11. This microfacies consists of light cream and grey colour. The limestone of this microfacies is granular and having medium to thick bedded. It consists of nodules and medium to coarse grain limestone. Fractures are present.

Petrographic Descriptions

The petrographic description of this microfacies show lack of fossils. This microfacies consists a large number of grains. The allochems (Peloidal Grainstone) percentage of this microfacies is 90% while the percentage of matrix is 10%.

Interpretation

The presence of Peloidal Grainstone depositional texture suggests that this microfacies is deposited in the environment of carbonate sand shoals and banks (Burchette and Wright,1992; Flugel and Munnecke, 2010). Peloids are micritized bioclasts, and their inner structures are either destroyed by organism activity or worn during the late stage of diagenesis. Peloids are commonly occurring in the mentioned environment (Flugel and Munnecke, 2010). The existence of peloidal grainstone depositional texture shows that the prevalence of Peloids and a low percentage of bioclasts suggest a restricted condition of deposition on the inner ramp in a lagoonal environment.This microfacies is correlated with standard microfacies RMF-27 of Wilson (1975) and Flugel (2004).

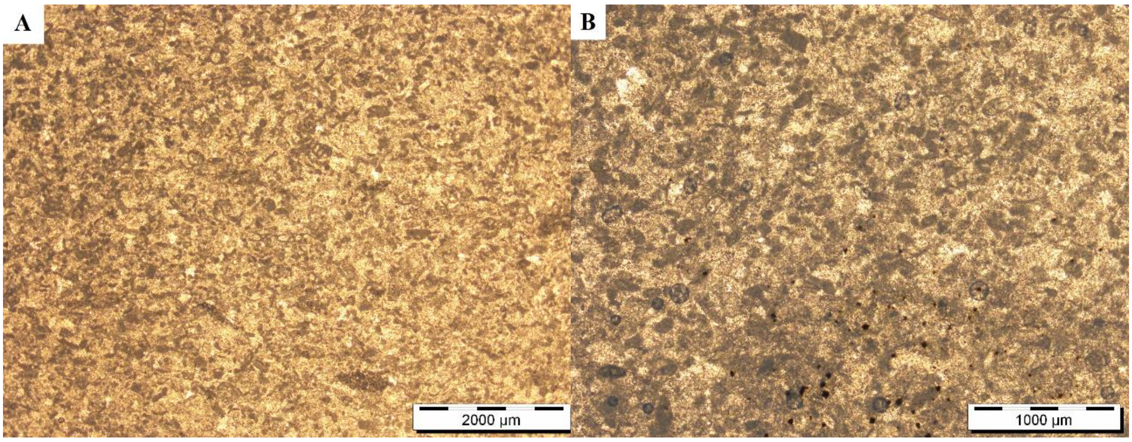


Figure 4.8: Photomicrographs showing Peloidal Grainstone (MFT-5): the allochems of this microfacies including Peloidal grains and micritic matrix in A & B.

4.4 Depositional Setting of Habib Rahi Limestone

The comprising plentiful skeletal allochems, micritic matrix, vertical dissemination of microfacies, relationship of different flora and fauna and construed depositional setting of individual microfacies of Habib Rahi Limestone increase overall deposition in shallow-marine, sub-tidal, semi restricted, lagoonal condition of inner-middle ramp environments (Figure 4.9). The dispersion of several larger benthic foraminifera and green algae, as well as other bioclasts,was investigated in the current study to determine the depositional environment of these predominantly micritic limestones.

During the Eocene period, at the time of deposition of Habib Rahi Limestone, there was an abundance of larger benthonic foraminifera and miliolidssp, predominantly Assilina sp, Alveolina sp, Nummulites, & Discocyclina (Mehr and Adabi 2014). Nummulites sp. were found in a variety of open-marine settings, including inner, middle, and even outer ramp settings (Racey, 2001; Beavington-Penney and Racey 2004). Relatively small lenticular to subglobular Nummulites occurs in inner ramp environments, frequently with Miliolids, Alveolina, and green algae, while large fat and discoidal Nummulites are found in moderately greater depths of middle to outer ramp environments, often with equally shaped Assilina sp. (Racey, 2001; BeavingtonPenney and Racey 2004; Vaziri-Moghaddam 2006).

Nummulites of medium to large size and lenticular-globular shapes prefer to live on middle ramps (Adabi et al., 2008). These regional patterns, with little variations, can be found in some early ramps (Sinclair et al. 1998). Racey (1994) suggested idealized faunal relationships with carbonate shelfenvironment during the Eocene period. The imperforate to perforate benthic foraminifera ratio is high in the proximal part of the inner ramp setting but decreases towards the distalportion of the middle shelf (Racey, 2001). As a result,larger benthic foraminifers are a useful indicator for modeling paleo-environments and reservoir potential in shallow-marine environments (Geel 2000; Racey 2001), and they are excellent markers for facies interpretation (Mehr and Adabi, 2014). Large benthic foraminifers and green algae were important carbonate builders in shallow marine ramp environments all over the world during the Eocene period (Racey, 2001; Wilson and Vecsei, 2005; Payros et al., 2010; Mehr and Adabi, 2014). The presence of benthic foraminifers in all microfacies indicates that they were deposited in the photic zone. Because they all have a symbiotic relationship with algae, benthonic larger foraminifers are now limited to the photic zone. Temperature and nutrient supply at greater depths, as well as photoinhibition and salinity near the sea surface, restrict the distribution of these foraminifera along the photic gradient(Hottinger, 1997; Hohenegger, 2000, 2004; Barattolo et al., 2007).

Nummulites are associated with eutrophic-oligotrophic conditions because the majority of their energy is considered to be derived from their symbiotic algae (Beavington Penney and Racey 2004; Swei and Tucker 2012). Dasycladale algae are found in warm water at shallower depths of only a few meters, where low water turbulence favors the presence of algae, particularly in semi restricted lagoonal and ramp environments. When compared to other Tethyan carbonate ramps, the presence of LBF in the Habib Rahi Limestone supports the preservation of a tropical to subtropical climate throughout deposition of this Formation (Buxton and Pedley 1989). Based on several recognized microfacies assemblages observed in Habib Rahi Limestone, delicate foraminifers to Algal dominated carbonate ramp depositional model is proposed for this formation (Figure 4.9).

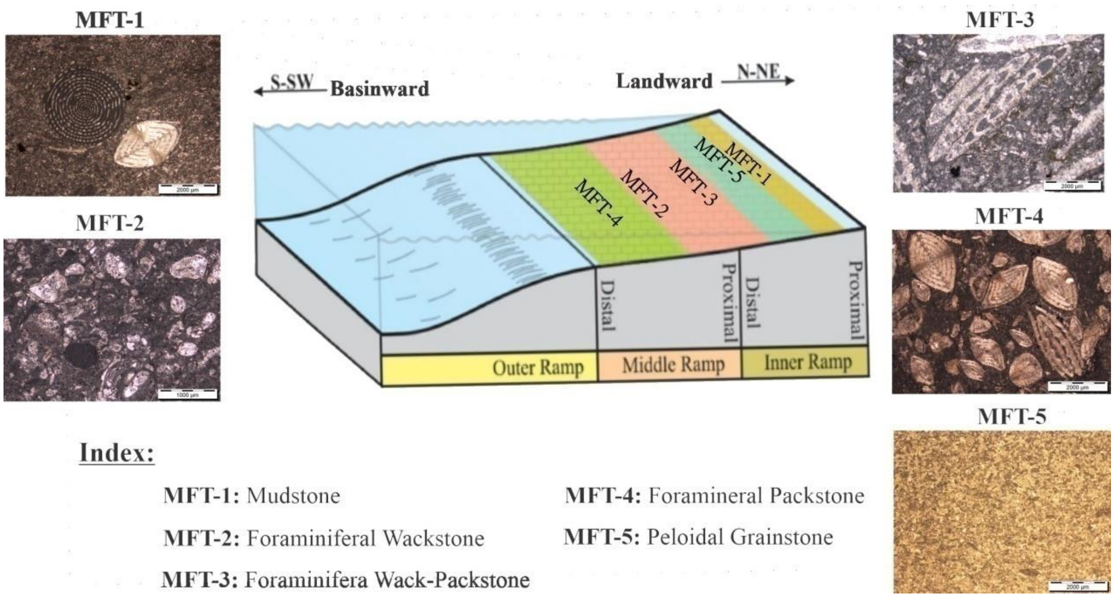


Figure 4.9 Proposed depositional model for Habib Rahi Limestone (modified after Flugel, 2010).

CHAPTER 5

DIAGENESIS AND RESERVOIR CHARACTERISTICS

5.1 Diagenetic Fabrics of the Habib Rahi Limestone

The diagenetic fabrics of the Habib Rahi Limestone were investigated to determine their diagenetic setting and the impact of diagenetic phases on the potential of the reservoir. The cross-cut relation serves as the foundation for the chronological sequence of diagenetic phases. Petrographic studies revealed that the Habib Rahi Limestone had been affected by a variety of diagenetic processes such as micritization, compaction, sparitization, cementation, Pyritization, recrystallization, stylolite, fracturing, and vein formation. Below is a detailed description of each diagenetic fabric.

5.1.1 Micritization

Micritization, also known as degrading recrystallization, takes place at the sediment-water interface when skeletal and non-skeletal grains are transformed and destroyed into structureless and homogeneous masses of transparent to opaque massive micrite under low energy conditions (Khalifa, 2005; Abu-El Ghar et al. 2015; Adams and MacKenzie 1998; Tucker and Wright 1990; Flügel, 2010). Micritization, which occurs in two phases, is the most essential and earliest diagenetic event in the Habib Rahi Limestone i.e., (i) Bioclast micritization occurs when micrites occupy the chambers of bioclasts (Figure 5.1), (Bathurst, 1975; Vincent, et al. 2007), (ii) Endolithic algae's repetitive activity on carbonate grain surfaces indicates the formation of micritic envelopes around bioclasts and other grains (Vincent, 2001; Carols, 2002; Vincent et al. 2007; Brigaud et al. 2009).

Micritization is noted in almost all samples of the Habib Rahi Limestone. The analysed samples are highly micritized and effected both skeletal grains and non-skeletal particles. It creates narrow micritic envelopes around specific grains and destroys the majority of the parts with micrite patches (Figure 5.1a). Micritization is the earliest event in both Habib Rahi Limestone and the paragenetic sequence (Vincent et al. 2007). This significant micritization in Habib Rahi Limestone shows that this process, as well as the resultant bioclast degradation structures, are evidence of strong microbial activity on the surface of carbonate grains.

5.1.2 Cementation

Cementation is the fundamental process by which loose particles become consolidated in early-stage diagenesis through the infilling of cementing materials in the pore spaces between these loose particles (McLane, 1995; Bathrust, 1982). In the studied section, Habib Rahi Limestone forms elevated ridges because it is well cemented. It is highly resistant to physical and chemical weathering due to its high cementation. Petrographically different thin sections were studied. Micritic mudstone, a product of early-stage marine diagenesis, is recognized as cementing material in all thin sections Figure 5.1b).

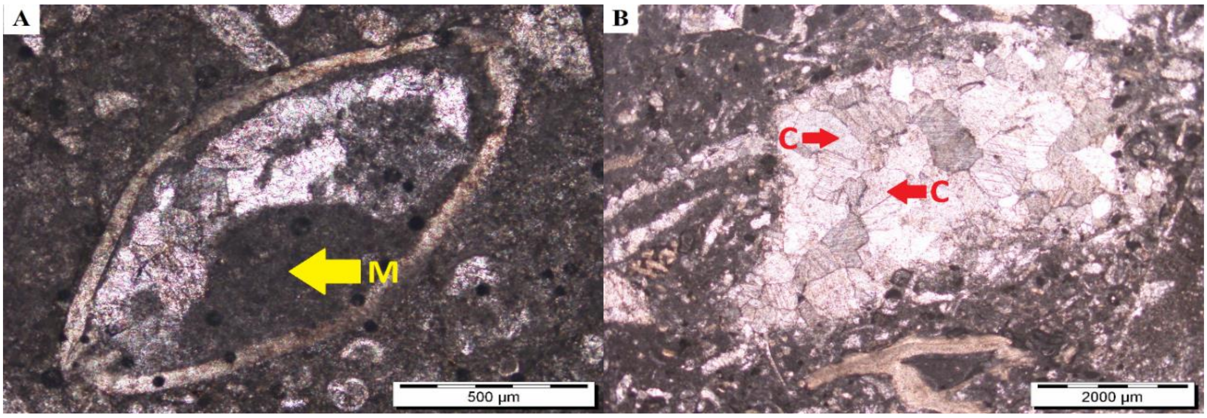
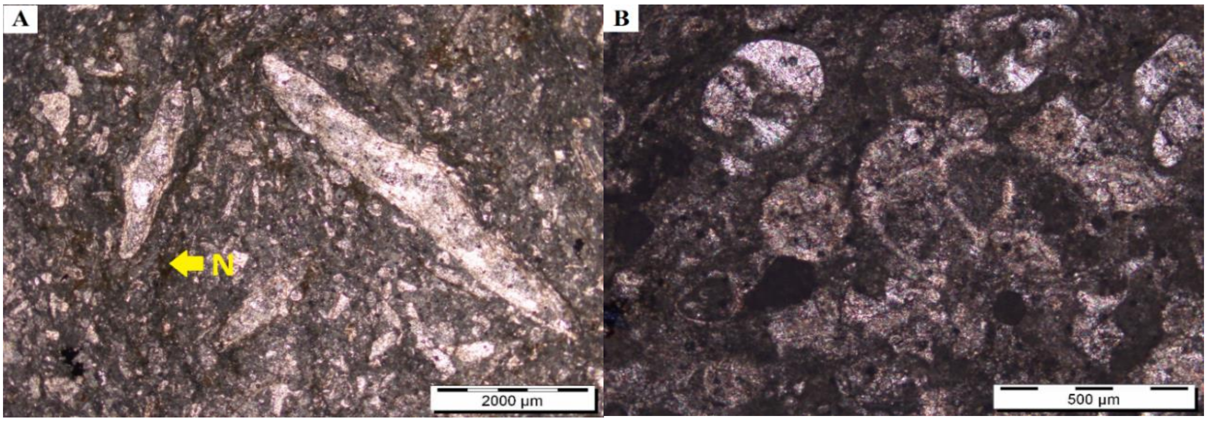


Figure 5.1 Photomicrographs showing micritization (M) in A, and in B showing cementation (C).

5.1.3 Neomorphism

Several neomorphic processes, such as replacement and recrystallization, are observed in the Habib Rahi Limestone. Recrystallization of micritic matrix and bioclast is a common occurrence.Calcite selectively replaces bioclasts is a common occurrence (Figure 5.2).



. **Figure5.2** Photomicrographs showing neomorphism (N) in A and B.

5.1.4 Sparitization

Folk introduces the term "Microspar" in 1959 to describe fine-grained inorganic calcite crystals having particle sizesfrom 4-30 microns (mostly 5-15microns). Micro spars, which often have a mosaic-like texture, must have a diagenetic origin.Petrographically, small white spots are observed in approximately every thin section/sample of Habib Rahi Limestone, which is known as a micro-spar. In Habib Rahi Limestone micro-spars are very common, especially in the middle and upper parts. Sparite fills the dissolution cavities in some portion of the thin section (Figure 5.3c).

5.1.5 Pyritization

The process of the development of various crystals of pyrite is referred as pyritization. In general, pyrite is formed under reducing conditions, most likely as a result of organic matter decay, which is caused by anaerobic bacteria, or a sulphate solution which is induced by reducing bacteria (Hudson, 1982). The crystals of pyrite were not visible in the outcrop. It may be owing to their small size, which is not visible tothe naked eye. According to petrography, the black blank spots are the crystals of pyrite. These crystals contain cubic and euhedral geometry. Approximately, pyrites were observed in most parts (figure 5.3d). The crystal sizes are too small, which could explain why they aren't seen at the outcrop. The abundance of pyrites suggests reducing the deep marine depositional environment.

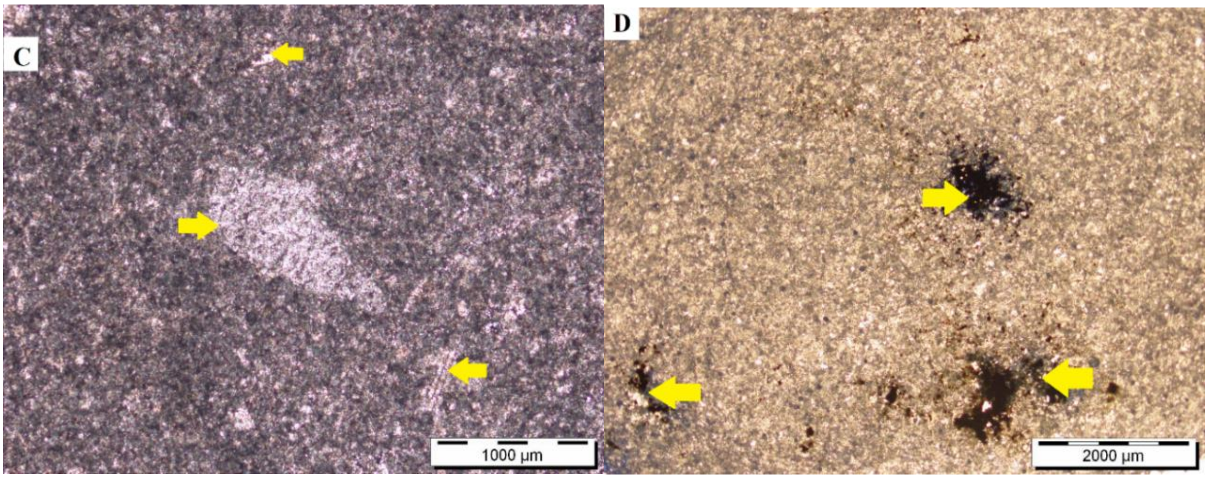


Figure 5.3 Photomicrographs showing micro spars and sparitization in C, while in D showing the crystals of pyrites.

5.1.6 Fracturing

Secondary porosity and permeability in carbonate rocks are mostly due to deformational fractures. Carbonate reservoirs hold between 50–60% oil and gas reserves of the world (Garland et al., 2012). Fracture is a term that refers to a naturally occurring planner discontinuity in rock that occurs as a result of deformation or physical diagenesis (Nelson, 2001). During different stages of sedimentation and diagenesis, the fracture system appears in carbonate rocks. Stress and shear displacement produce tectonic fracturing and brittle failure of lithified rocks of carbonate, resulting in calcite filled veins. Micro fractures are also formed by extensional movements and natural hydraulic fracturing (Sibson, 1975). Both filled and un-filled fracturing can be seen at outcrops (Figure 5.4a), however, the ratio of fractures is low in some places. The low number of fractures could be related to the significant amount of mud and minor content of allochems. Based on petrography, filled and un-filled fractures were identified.The fractures are filled with calcite. These fractures cut across allochems and other fractures indicating that the occurrences are multi-staged (Figure 5.4a)

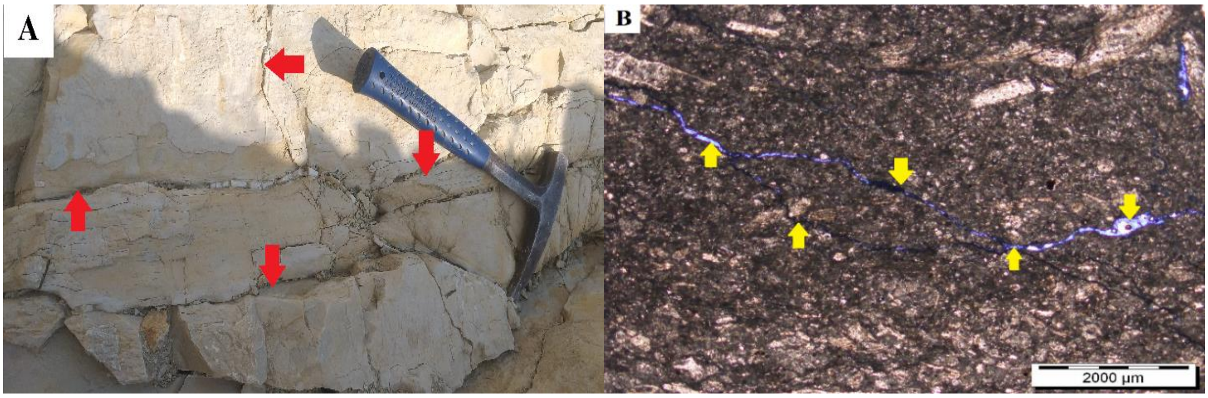


Figure 5.4 Photomicrographs showing the cross-cut fracture and calcite filled fracture in A, while in B showing fracture porosity.

5.1.7 Recrystallization

Due to high temperature and pressure conditions, primary rock fabrics are recrystallized into new fabrics later in deep burial diagenesis. Few portions of the outcrop were highly crystallized, due to which it is not possible to identify the primary sedimentary features. Well-developed crystals can be found in recrystallized portions. Recrystallization occurs frequently in limestone facies (figure 5.5a,b).

5.1.8 Dissolution

Dissolution is frequently observed at outcrop, as well as in petrography and SEM analysis (figure 5.7). The dissolution in Habib Rahi Limestone is divided into two stages: first, the dissolution of the micritic matrix during the early stages of marine diagenesis as a result of methane exaltations during algal organic matter decay (Flugel, 2004). This type of dissolution is common in mud-stone, Wackstone microfacies of lagoons, and mudflats.Calcite grain dissolution, cement stylolitization, and fracture enlargement characterise the second stage. The breakdown of the stylolites and fractures occurs after the early diagenetic phase because they formed during burial diagenesis. Under high energy shoal setting, carbonate cement precipitates in pore spaces of allochems. These high energy-shoal environments have a diverse variety of primary pore spaces (Flugel, 2004). Organic matter preservation is limited because these pore spaces are constantly refilled with marine water. As a result, cement disintegration during the early stages of diagenesis may not be linked to decaying organic materials.

5.1.9 Stylolites

The formation of stylolites is the result of a physio - chemical process caused by burial compaction and tectonic compression (Buxton and Duncan, 1981). Stylolites have significant roughness on their surfaces, as well as teeth and penlike geometries. The identification of stylolites on outcrop is difficult since there are stylolites, but they are too small to distinguish from thin fractures. Petrographically, wavy-like structures such as the ECG shape are known as stylolites. The stylolites in the Habib Rahi Limestone cross cut all of the diagenetic fabric evenly, indicating its late stage of occurrences (Figure 5.5c, d).

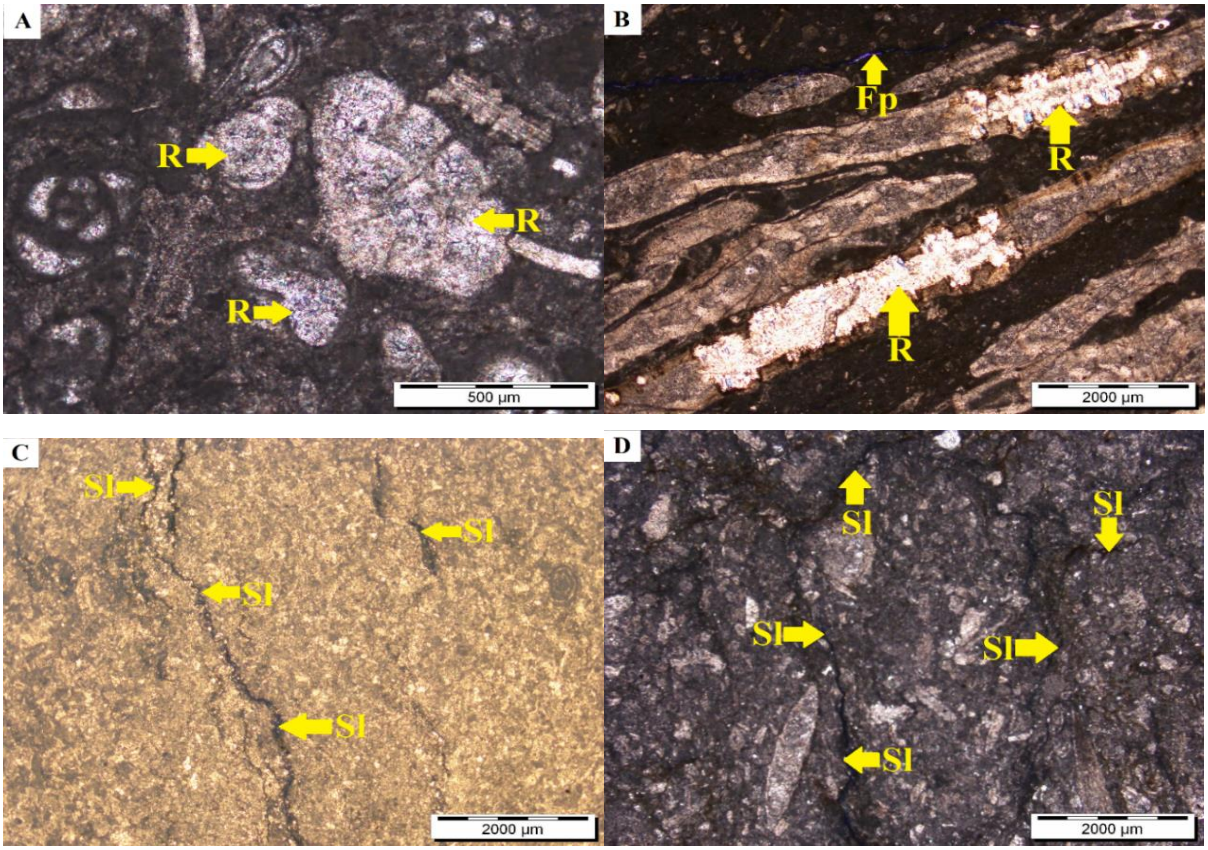


Figure 5.5 Photomicrographs showing recrystallization (R) in A & B, and stylolites are showing in photomicrographs C & D.

5.2 Evolution of diagenesis

- The earliest stage in the Habib Rahi Limestone after deposition is micritization, and in in the paragenetic sequence (Vincent et al. 2007).
- All of the allochems are well cemented, cementation took at the next early-stage of marine diagenesis.

- Pyritization occurs during the early stages of burial (Larsen and Chilingar, 1979). Pyrites can be found in abundance in Habib Rahi Limestone.
- Fracture occurs at various stages in carbonate rocks (Sibson, 1975). The filled fractures are abundant in Habib Rahi Limestone.
- Recrystallization can be seen in some parts of the Habib Rahi Limestone.The entire fabric is missing in the recrystallized portion, indicating that it happened at a late-stage of diagenesis.
- Stylolites form during burial or as a result of tectonic compaction (Buxton and Duncan, 1981). According to petrographic observations, it is a postdiagenetic feature because it crosscuts all fabrics.

5.3 Reservoir Characterization

Petrographic studies are used to conduct a qualitative reservoir assessment of the Eocene Habib Rahi Limestone from outcrop data. Petrographic study on microscopic and mesoscopic scales was used to identify the porosity types in the Habib Rahi Limestone. i.e., visual porosity and diagenetic features, is used.

5.3.1 Macro porosity

At the outcrop, large scale fractures, cavities, vugs, and stylolites were observed, all of which contributed to the porosity of the Habib Rahi Limestone. Fractures of varying sizes, spacing, pattern, and orientation were observed.The extensive interconnectivity of these fractures may have played a substantial role to the effective porosity. There were both low-amplitude and high-amplitude stylolites found. The reservoir segment of the Habib Rahi Limestone may be compartmentalized as a result of significant stylolitization with concentrated insoluble residue.Moreover, calcite precipitated by pressure solution maybe precipitated in fractures as well as other pores, thereby obstructing the porosity of unit (Ehrenberg, Morad, Yaxin, & Chen, 2016).The disintegration of allochems, matrix, and fractures resulted in cavities and vugs at the macroscopic level, as shown in the studies section.

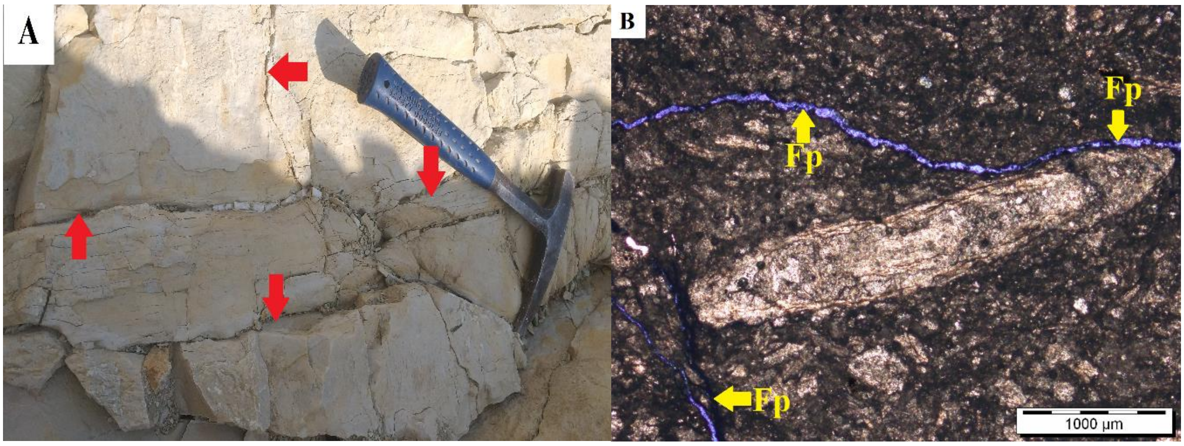


Figure 5.6 Photomicrographs showing fracture porosity in both outcrop image (A) and thin section image (B).

5.3.2 Microporosity

Different types of porosity were identified using petrography and SEM analysis, including inter-crystalline, fracture, and dissolution porosity (Figure 5.7). SEM analysis revealed the intergranular porosity (Figure 5.8).Micro pores between the small grains comprise the intergranular porosity. In the micritic matrix, it was equally distributed. The dissolution of allochems, matrix, cement, and fractures were revealed by SEM and Petrographic analysis. Under the microscope and SEM, open fractures were identified. The fact that these fractures are un-filled indicates that they are still in their early stages of development.Except for microcrystalline porosity, the most common identified porosity types in the Habib Rahi Limestone are secondary in origin. Fracture porosity is the most typically recognised secondary porosity type in the Habib Rahi Limestone, and it is crucial in the development of porosity and the formation of fluid flow paths.

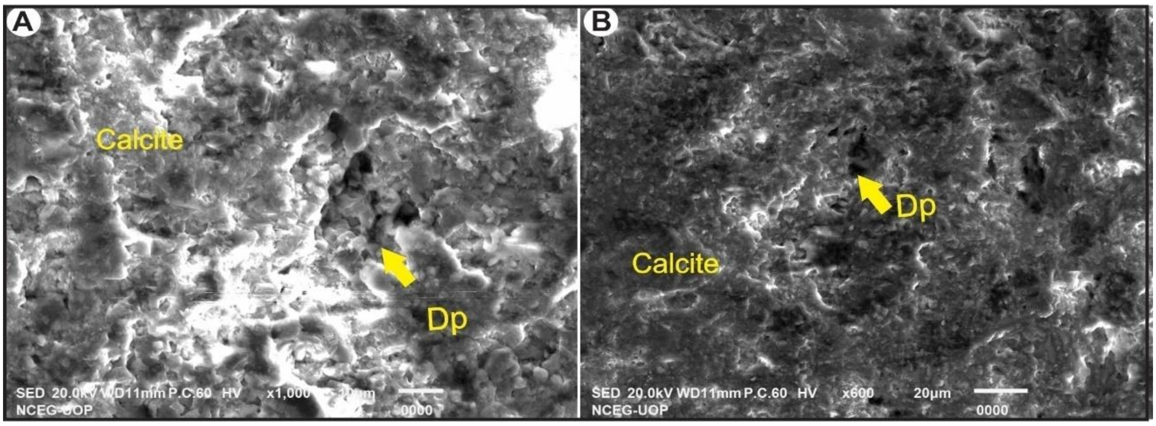


Figure 5.7 Scanning electron microscopy (SEM) photographs showing calcite with dissolution porosity (Dp) in A and B.

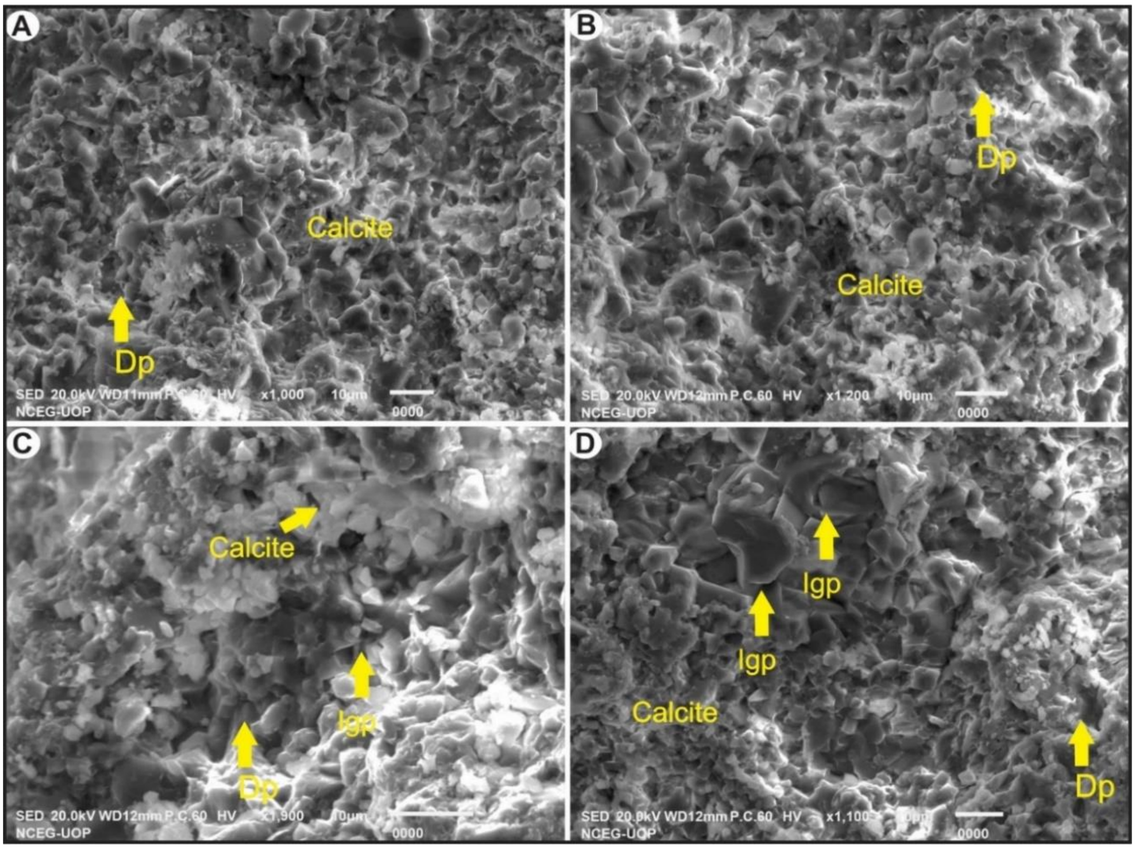


Figure 5.8 Photomicrographs showing the Scanning electron microscopy (SEM) of Habib Rahi Limestone showing calcite with intergranular porosity (Igp) and dissolution porosity (Dp) in A and B, (C and D).

5.4 Paragenetic sequence and diagenetic environments

The sequence of diagenetic events in carbonate rocks is determined by sediment, texture, grain size, pore fluid type, mineralogy and climate conditions (Tucker and Wright 1990; Flügel 2010). The diagenetic environments of the Habib Limestone were differentiated and designated as marine, meteoric, burial, and uplift realms, based on diagenetic characteristics, mineralogical compositions, cement types and occurrences, and microfabrics. Each of these diagenetic environments has unique characteristics and diagnostic features, which are discussed briefly below. Figures 5.9 and 5.10 indicate the diagenetic model and paragenetic sequence of Habib Rahi Limestone.

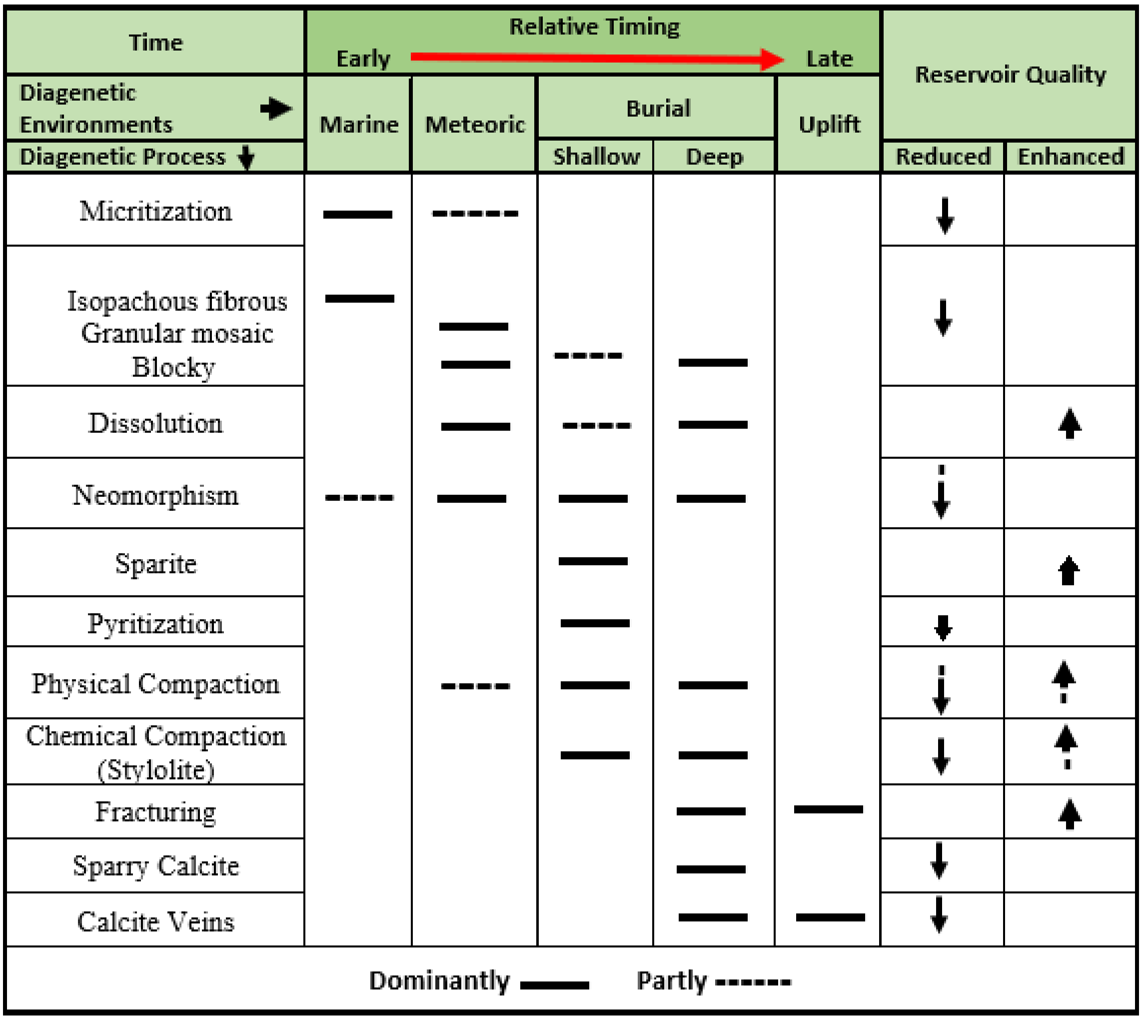


Figure 5.9 The paragenetic sequence of several diagenetic fabrics and their impact on the reservoir quality of Habib Rahi Limestone (modified after Ishaq et al., 2018).

5.4.1 Marine diagenetic Environment

The first generation of micritization recognises marine diagenetic environments (Abu-El Ghar et al. 2015). The predominant diagenetic feature recognised in Habib Rahi Limestone is micritization, which is thought to have formed in a marine environment. Micritization in the Habib Rahi Limestone is severe, with micritic envelopes as well as skeletal micritization which may have resulted from mechanical disintegration or bioerosion of large calcareous organisms, such as Nummulites, Alveolina, or algae, by endolithic algae (Abu-El Ghar and Hussein 2005; Khalifa 2005).

5.4.2 Meteoric diagenetic environment

The carbonates were subjected to meteoric diagenesis after early marine diagenesis (Figure 5.10). Macroscopic dissolution, granular mosaic cement, and drusy mosaic cement are the diagenetic features of meteoric diagenesis. These are the meteoric diagnostic indicators of meteoric diagenesis (Tavakoli, Rahimpour-Bonab, &Esrafili-Dizaji, 2011). Vugs and molds have formed as a result of the meteoric dissolution of unstable skeletal or non-skeletal sediments. Because it has dissolved the early marine cementation, this phase of diagenesis predates the early marine diagenesis.Meteoric diagenesis does not enlarge or fill the pore spaces associated with stylolites, dolomite, and fractures, and implying that it predates burial diagenesis.

5.4.3 Burial diagenetic environment

The Habib Limestone has been passed through burial diagenesis, based on the observed diagenetic fabrics, chemical compaction, mechanical compaction recrystallization, and nodularity, show an overall burial diagenetic domain for the Habib Rahi Limestone, with fractures, veins, blocky and granular calcite cement, stylolites and dissolution seams, and nodular fabric of limestone (Mahboubi et al. 2010). The burial diagenetic realms are divided mainly into shallow burial and deep burial, but the exact boundary is uncertain (Vincent et al. 2007; Flügel 2010). Mechanical compaction can also be affected by varying porosity reduction (Abuseda et al. 2015). The shallow burial realm is characterised by the features of chemical compaction such as stylolites and dissolution seams (Mahboubi et al. 2010; Abuseda et al. 2015). The development of nodular fabric is supported by both diagenetic and tectonic processes. The development of fractures, veins, blocky calcite,and later stage of selective dissolution of blocky cement and vein formed in deep burial realm.

5.4.4 Uplifting

After uplifting, the Habib Limestone was impacted by late diagenetic episodes, which resulted in the formation of fractures by the Alpine-Himalayan orogenies when the basin was folded and faulted during the Eocene period. Calcite cement has been used to fill certain fractures. The most prominent processes that contributed to secondary porosity in this interval are dissolution and fracturing.

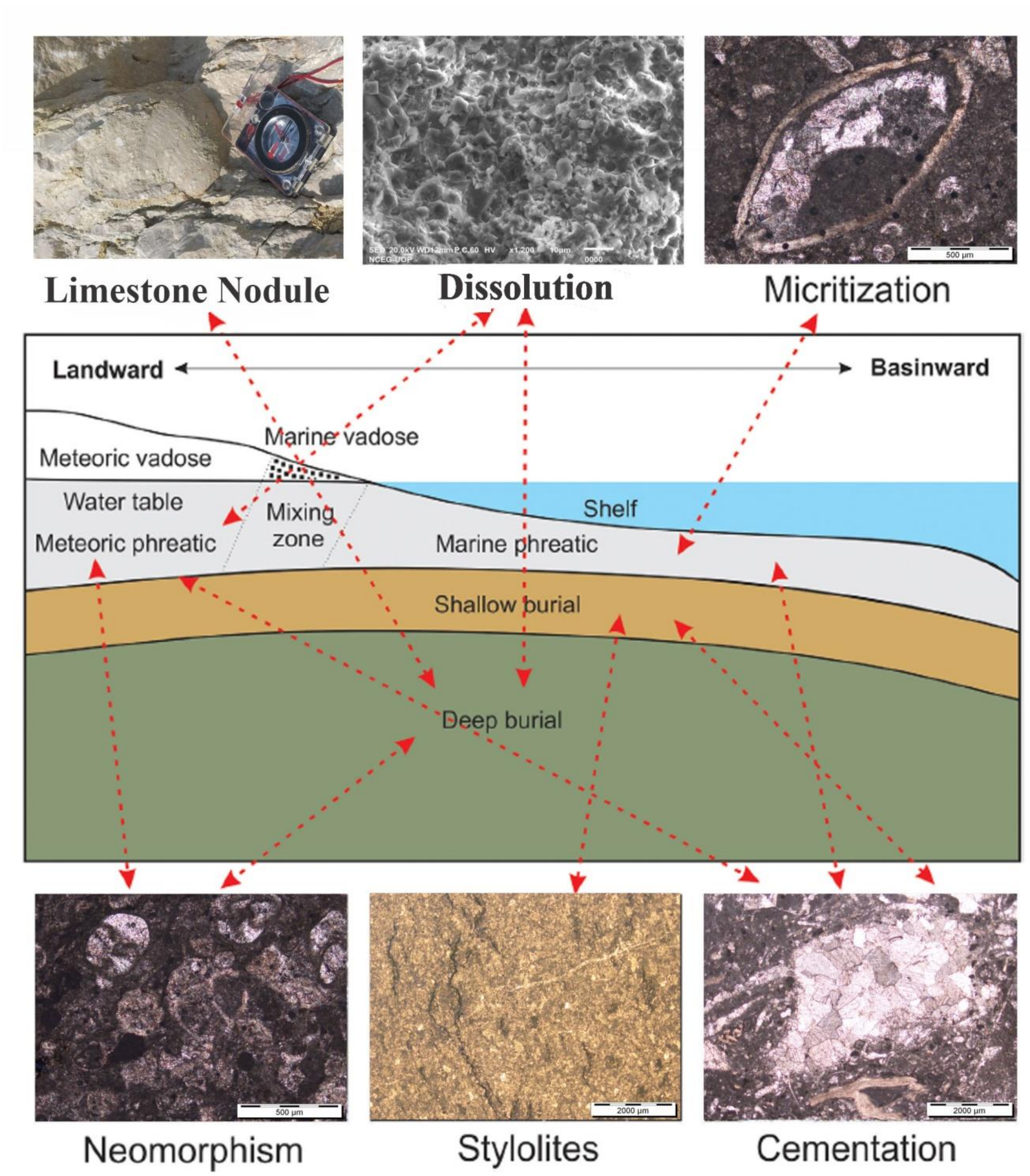


Figure 5.10 Schematic diagenetic environments proposed for the Habib Rahi Limestone, a typical carbonate platform (modified after Flugel, 2010).

Based on the diagenetic features discussed above, it is observed that the Habib Rahi Limestone, Shinki Post, North Waziristan section, went through all diagenetic environments, i.e., marine, meteoric, burial, and uplifting, as evidenced by the various phases of diagenesis observed. Each phase is distinguished by a distinct diagenetic environment. Micritization, dissolution, neomorphism, compaction, fracturing, cementation, and mechanical and chemical compaction are all used to unravel each diagenetic environment. A paragenetic sequence was developed based on the relative timeframe of diagenesis (Figure 5.9).

As a result of these processes, the reservoir quality of the formation has been affected and redistributed. Porosity has been reduced in many scenarios, while in some cases it has been enhanced. Porosity is increased at some intervals due to less cementation. Most of Pakistan's Eocene reservoirs produce hydrocarbon through fractures widened by partial disintegration of cement within fractures at a later stage (Figure 5.6a). In some cases, spar was used to seal fractures, and early-stage dissolution retained porosity that had already formed.Calcite partial dissolution within previously formed fracturesincreased secondary porosity. Compressive tectonics or burial caused the limestone fractures (e.g., Swennen et al. 2003; Vincent et al. 2007; Flügel 2010). In the Habib Rahi Limestone, minor stylolitic porosity was observed (Figure 5a). However, the porosity of Eocene limestone has been significantly reduced by compaction and cementation. Because of component grain breakage, mechanical compaction resulted in a slight increase in porosity. The porosity of the Eocene limestone increased as a result of dissolution. Porosity was reduced in the samples studied due to physical compaction caused by increasing sediment overburden.

5.5 Diagenetic impacts on the reservoir potential

The Habib Rahi Limestone, which is exposed in the studied area, is the best analog for investigating the impact of diagenesis on the reservoir quality of Early Eocene carbonates. The reservoir quality of the Habib Rahi Limestone's different lithological units has been affected by marine, meteoric, and burial diagenesis. Carbonate reservoir quality can be increased or degraded as a result of such modifications (Abuseda et al. 2015). The studied section of the Habib Rahi Limestone is composed of three lithological units. According to outcrop investigations, some lithological units are highly inter-connected fractures with varying spacing. The fractures may have increased the effective porosity of the units. Despite this, the presence of irregular calcite-filled veins has caused the fracture porosity to be destroyed. By enhancing insoluble residue, low to high amplitude stylolites in all strata may have separated reservoir sections at distinct stratigraphic levels. However, the fractures have cut over the stylolites and formed into intervals, allowing fractures to interconnect and thus increase the effective porosity. Petrographic studies have also demonstrated that diagenetic alterations have significantly influenced the reservoir quality of the Habib Rahi Limestone, such as the dominance of micro-dissolution and micro-fractures porosities within the mudstone to packstone microfacies are observed. Such porosity types do not exist in grainstone microfacies. According to different sorts of microscopic porosities, mudstone to packstone has good reservoir quality, but grainstone has poor prospects.

CONCLUSION

- In Habib Rahi Limestone, five microfacies are recognized which represent proximal inner ramp to distal middle ramp depositional environment i.e., Mudstone (MFT-1),Foraminiferal Wackstone (MFT-2), Wack-Packstone (MFT-3) (Assilina Wack-Packstone & Alveolina Wack-Packstone), Packstone (MFT-4) (Nummulitic Packstone & Assilina Packstone) and Peloidal Grainstone (MFT-5).
- Based on diagenetic fabrics, a paragenetic sequence is established (i.e., micritization, cementation, dissolution, neomorphism,pyritization, chemical and mechanical compaction, fractures and veins) revealing that the Habib Rahi Limestone experienced marine, meteoric, burial, and uplift realm diagenesis.
- The genetic porosity types (including depositional, diagenetic, and fracture) have been identified;fracture porosity has emerged as the dominant type of porosity. Other types of porosity recognised as dissolution porosity and intergranular porosity.
- Based on the SEM analysis, the identified microporosities are intergranular, dissolution, microfracture. Among these microporosities dissolution and intergranular are the dominant porosities that can play effective roles to act the Habib Rahi Limestone as a good reservoir.
- The dissolution and fracture of the Habib Rahi Limestone increase its reservoir potential and make it a productive hydrocarbon reservoir, whereas other diagenetic features decreases its reservoir potential.

REFERENCES

A. Dilks, S. C. Graham. (1985). Quantitative Mineralogical Characterization of Sandstones by Back-Scattered Electron Image Analysis. *SEPM Journal of Sedimentary Research, Vol. 55*. doi: 10.1306/212f86c5-2b24-11d7-8648000102c1865d.

Abu El Ghar, M., Khalifa, M., & Hussein, A. (2014). Carbonate diagenesis of the mixed clastic–carbonate Galala Formation, North Eastern Desert, Egypt. *Arabian Journal Of Geosciences*, *8*(5), 2551-2565. doi: 10.1007/s12517-014-1349-3.

Abuseda, H., Kassab, M., LaLa, A., & El Sayed, N. (2015). Integrated petrographical and petrophysical studies of some Eocene carbonate rocks, Southwest Sinai, Egypt. *Egyptian Journal Of Petroleum*, *24*(2), 213-230. doi: 10.1016/j.ejpe.2015.05.006

Adabi, M., Zohdi, A., Ghabeishavi, A., & Amiri-Bakhtiyar, H. (2008). Applications of nummulitids and other larger benthic foraminifera in depositional environment and sequence stratigraphy: an example from the Eocene deposits in Zagros Basin, SW Iran. *Facies*, *54*(4), 499-512. doi: 10.1007/s10347-008-0151-7.

Afzal, J. (1996). Late Cretaceous to Early Eocene Foraminiferal Biostratigraphy of the Rakhi Nala Area, Sulaiman Range, Pakistan: Pak. Jour. Hydrocarbon Res., v.8, no.1, p.86-96.

Afzal, J., Asrar, M., Naseer, A. (1997). Biostratigraphy of the Kirthar Formation (Middle to Late Eocene), Sulaiman Basin, Pakistan. Pakistan Journal of Hydrocarbon Research 9, 15-33.

Ahmad., Ali, F., Rehman, N., & Gul, J. (2000). Lithostratigraphy of the Kurram Group along Mirali-Miran Shah Road, North Waziristan Agency, NWFP, Pakistan. Geol. Bull. Univ. of Peshawar, vol. 33, pp.79-86.

Ali, A., Wagreich, M., & Strasser, M. (2018). Depositional constraints and diagenetic pathways controlling petrophysics of Middle Miocene shallow-water carbonate reservoirs (Leitha limestones), Central Paratethys, Austria-Hungary. *Marine And Petroleum Geology*, *91*, 586-598. doi: 10.1016/j.marpetgeo.2018.01.031.

Ali, F., Haneef, M., Anjum, M.N., Hanif, M., & Khan, S. (2013). Microfacies analysis and sequence stratigraphic modeling of the Samana Suk Formation, Chichali Nala, Trans Indus Ranges, Punjab, Pakistan. *Journal of Himalayan Earth Science,* 46(1), 41-53.

Amel, H., Jafarian, A., Husinec, A., Koeshidayatullah, A., &Swennen, R. (2015). Microfacies, depositional environment and diagenetic evolution controls on the reservoir quality of the Permian Upper Dalan Formation, Kish Gas Field, Zagros Basin. *Marine And Petroleum Geology, 67,* 57-71. doi: 10.1016/j.marpetgeo.2015.04.012.

Anketell, J., and Mriheel, I. (2000). Depositional Environment and Diagenesis of the Eocene Jdeir Formation, Gabes-Tripolo Basin, Western Offshore, Libya. *Journal of Petroleum Geology*, 23(4), pp.425-447.

Badshah, M., Gnos, E., Jan, M., & Afridi, M. (2000). Stratigraphic and tectonic evolution of the northwestern Indian plate and Kabul Block. *Geological Society, London, Special Publications*, *170*(1), 467-476. doi: 10.1144/gsl.sp.2000.170.01.25.

Barattolo, F., Bassi, D., & Romano, R. (2007). Upper Eocene larger foraminiferal–coralline algal facies from the Klokova Mountain (southern continental Greece). *Facies*, *53*(3), 361-375. doi: 10.1007/s10347-007-0108-2.

Bathurst, R. (1982). Genesis of stromatactis cavities between submarine crusts in Palaeozoic carbonate mud buildups. *Journal Of The Geological Society*, *139*(2), 165-181. doi: 10.1144/gsjgs.139.2.0165.

Bathurst, R. G. C. (1975). Carbonate sediments and their diagenesis (developments in sedimentology 12). Elsevier, Amsterdam.

BEAVINGTONPENNEY, S. (2004). Ecology of extant nummulitids and other larger benthic foraminifera: applications in palaeoenvironmental analysis. *Earth-Science Reviews*, *67*(3-4), 219-265. doi: 10.1016/j.earscirev.2004.02.005.

Beck, R., Burbank, D., Sercombe, W., Khan, A., & Lawrence, R. (1996). Late Cretaceous ophiolite obduction and Paleocene India-Asia collision in the western most Himalaya. *Geodinamica Acta, 9(2-3),*114-144. doi: 10.1080/09853111.1996.11105281.

Beck, R., Burbank, D., Sercombe, W., Riley, G., Barndt, J., & Berry, J. et al. (1995). Stratigraphic evidence for an early collision between northwest India and Asia. *Nature*, *373*(6509), 55-58. doi: 10.1038/373055a0.

Beigi, M., Jafarian, A., Javanbakht, M., Wanas, H., Mattern, F., & Tabatabaei, A. (2017). Facies analysis, diagenesis and sequence stratigraphy of the carbonate-evaporite succession of the Upper Jurassic Surmeh Formation: Impacts on reservoir quality (Salman Oil Field, Persian Gulf, Iran). *Journal Of African Earth Sciences*, *129*, 179-194. doi: 10.1016/j.jafrearsci.2017.01.005.

Brigaud, B., Durlet, C., Deconinck, J., Vincent, B., Thierry, J., &Trouiller, A. (2009). The origin and timing of multiphase cementation in carbonates: Impact of regional scale geodynamic events on the Middle Jurassic Limestones diagenesis (Paris Basin, France). *Sedimentary Geology*, *222*(3-4), 161-180. doi: 10.1016/j.sedgeo.2009.09.002.

Brown, J. (1943). Suggested use of the word microfacies. *Economic Geology*, *38*(4), 325-0. doi: 10.2113/gsecongeo.38.4.325.

Burchette, T., & Wright, V. (1992). Carbonate ramp depositional systems. *Sedimentary Geology*, *79*(1-4), 3-57. doi: 10.1016/0037-0738(92)90003-a.

BUXTON, M., & PEDLEY, H. (1989). Short Paper: A standardized model for Tethyan Tertiary carbonate ramps. *Journal of the Geological Society*, *146*(5), 746-748. doi: 10.1144/gsjgs.146.5.0746.

Buxton, T., & Sibley, D. (1981). Pressure solution features in a shallow buried limestone. *Journal Of Sedimentary Research*, *51*(1), 19-26. doi: 10.1306/212f7bf8-2b24-11d7-8648000102c1865d.

Carols, L. (2002). Diagenetic history of the Upper Jurassic Smackover formation and its efects on reservoir properties: vocation feld, Manila Sub-Basin, Eastern Gulf Coastal Plain. Gulf Coast Assoc Geol Soc Trans 52:631–644.

Dunham, R. J. (1962). Classification of carbonate rocks according to depositional texture. In: Ham WE (ed) Classification of carbonate rocks. Memoir American Association of Petroleum Geologists, vol 1, pp 108–121.

Ehrenberg, S., Morad, S., Yaxin, L., & Chen, R. (2016). Stylolites and Porosity in A Lower Cretaceous Limestone Reservoir, Onshore Abu Dhabi, U.A.E. *Journal of Sedimentary Research, 86*(10), 1228-1247. doi: 10.2110/jsr.2016.68.

Fan, T. L., Yu, B. S., & Gao, Z. Q. (2007). Characteristics of carbonate sequence stratigraphy and its control on oil gas in Tarim Basin. Geoscience 21(1):57–65.

Farah, A., Lawrence, R. D., & De Jong, K. A. (1984). An overview of the tectonics of Pakistan. In B. U. Haq& J. D. Milliman (Eds), Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan. (pp. 161–176). Van No Strand and Reinhold Company.

Fatmi, A. N., & Khan, M. R. (1966). Stratigraphy of the part of western Kohat, West Pakistan (Samana-Darsamand-Thal Sections). Geol. Surv. Pak., Pre. Publ.Issue., 20, 1-65.

FLÜGEL, E. (2004). Microfacies of Carbonate Rocks. Analysis, Interpretation and Application. xx + 976 pp. Berlin, Heidelberg, New York: Springer-Verlag. Price Euros 99.95 (+ VAT at local rate), SFr 169.00, £77.00, US $99.00 (hard covers). ISBN 3 540 22016 X. *Geological Magazine*, *143*(1), 137-138. doi: 10.1017/s0016756806221940.

FLÜGEL, E. (2010). Microfacies of carbonate rocks: analysis, interpretation and application, 2nd edn. Springer, Berlin. https://doi. org/10.1007/978-3-642-03796-2.

FLÜGEL,E., Munnecke, A. (2010) Microfacies of carbonate rocks: analysis, interpretation and application. Springer-Verlag.

Folk, R., L. (1959). Practical petrographic classification of limestone. AAPG Bulletin, 43, 1-38.

Folk, R., L. (1962). Spectral subdivision of limestone types. American Association of Petroleum Geologists. Memoir 1, p. 62-84.

Friedman, R., Gee, J., Tauxe, L., Downing, K., & Lindsay, E. (1992). The magnetostratigraphy of the Chitarwata and lower Vihowa formations of the Dera Ghazi Khan area, Pakistan. *Sedimentary Geology*, *81*(3-4), 253-268. doi: 10.1016/0037-0738(92)90074-2.

Friend, P. (1984). Book reviews : Davis, R.A. 1983: Depositional systems: a genetic approach to sedimentary geology. Englewood Cliffs: Prentice Hall. xvii + 669 pp. £31.45. *Progress In Physical Geography: Earth and Environment*, *8*(4), 619-620. doi: 10.1177/030913338400800412.

Garland, J., Neilson, J., Laubach, S. E., Whidden, K. J. (2012). Advances in carbonate exploration and reservoir analysis. Geological Society, London, Special Publications, 370, 1-15.

Geel, T. (2000). Recognition of stratigraphic sequences in carbonate platform and slope deposits: empirical models based on microfacies analysis of Palaeogene deposits in southeastern Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *155*(3-4), 211-238. doi: 10.1016/s0031-0182(99)00117-0.

Gressly, A. (1838). Observations géologiques sur le Jura soleurois: Nouveaux mémoires de la Société Helvetique des Sciences Naturelles, Neuchâtel, v. 2, 349 p., 14 pl.

H. R. Tainsh (2), K. V. Stringer (2. (1959). Major Gas Fields of West Pakistan. *AAPG Bulletin*, *43*. doi: 10.1306/0bda5f3f-16bd-11d7-8645000102c1865d.

Hernphill, W., & Kidwai, A. H. (1973). Stratigraphy of the Bannu and D. I. Khan areas, Pakistan. U.S.G.S Prof. Paper, 716-B, 36p**.**

Hohenegger, J. (2000). Coenoclines of larger foraminifera. Micropaleontology 46:127–151.

Hohenegger, J. (2004). Depth coenoclines and environmental considerations of western Pacifc larger foraminifera. J Foraminifer Res 34:9–33.

Hottinger, L. (1997). Shallow benthic foraminiferal assemblages as signals for depth of their deposition and their limitations. Bull de la Société géologique de France 168:491–505.

Hudson, J. D. (1982). Pyrite in ammonite bearing shales from the Jurassic of England and Germany. Sedimentology, 29, 639−667.

Iqbal, M.W.A. (1969). The Tertiary pelecypod and gastropod fauna from Drug, ZindaPir, Vidor (Distt. D.G. Khan), Jhalar and Charrat (Distt. Campbellpur), West Pak. GSP. Mem. Paleont. Pakistanica**(6)**: 77Pp.

Jafarian, A., Javanbakht, M., Koeshidayatullah, A., Pimentel, N., Salad Hersi, O., Yahyaei, A., &Beigi, M. (2017). Paleoenvironmental, diagenetic, and eustatic controls on the Permo-Triassic carbonate-evaporite reservoir quality, Upper Dalan and Kangan formations, Lavan Gas Field, Zagros Basin. *Geological Journal*, *53*(4), 1442-1457. doi: 10.1002/gj.2965.

Jaumé, S., & Lillie, R. (1988). Mechanics of the Salt Range-Potwar Plateau, Pakistan: A fold-and-thrust belt underlain by evaporites. *Tectonics*, *7*(1), 57-71. doi: 10.1029/tc007i001p00057.

Jiang, H., Song, X., & Wang, Y. (2008). Current situation and forecast of the world's carbonate oil and gas exploration and development. Ofshore Oil 28(4):6–13.

Kadri, IB. (1995). Petroleum geology of Pakistan. Pak Petrol Ltd Karachi Pak 275:429–438.

Kakar, M., Collins, A., Mahmood, K., Foden, J., & Khan, M. (2012). U-Pb zircon crystallization age of the Muslim Bagh ophiolite: Enigmatic remains of an extensive pre-Himalayan arc. *Geology*, *40*(12), 1099-1102. doi: 10.1130/g33270.1.

Kazmi, A. H., & Abbasi, I. A. (2008). Stratigraphy and Historical Geology of Pak. Published by Dept. and NCE in Geology, Univ. of Peshawar, Pak. 524Pp.

Kazmi, A. H., & Jan, M. Q. (1997). Geology and tectonics of Pakistan. Graphic publishers.

Kazmi, A. H., & Rana, R. A. (1982). Tectonic Map of Pakistan 1: 2 000 000: Elite Print.

Kenter, J., Harris, P., & Della Porta, G. (2005). Steep microbial boundstone-dominated platform margins—examples and implications. *Sedimentary Geology*, *178*(1-2), 5-30. doi: 10.1016/j.sedgeo.2004.12.033.

Khalifa, M. (2005). Lithofacies, diagenesis and cyclicity of the 'lower member'of the Khuf formation (late Permian), Al Qasim Province, Saudi Arabia. J Asian Earth Sci 25:719–734.

KhatibiMehr, M., &Adabi, M. (2013). Microfacies and geochemical evidence for original aragonite mineralogy of a foraminifera-dominated carbonate ramp system in the late Paleocene to Middle Eocene, Alborz basin, Iran. *Carbonates And Evaporites*, *29*(2), 155-175. doi: 10.1007/s13146-013-0163-4.

Khitab, U., Umar, M., & Jamil, M. (2020). Microfacies, diagenesis and hydrocarbon potential of Eocene carbonate strata in Pakistan. Carbonates and Evaporites, 35(3). doi:10.1007/s13146-020-00601-9.

Khurshid, A., R. Nazirullah., & Lillie, R. J. (1992). Crustal structure of the Sulaiman Range, Pakistan from gravity data: Pakistan Journal of Hydrocarbon Research, v. 4, no. 1, p. 9–30.

La Touche, T.D. (1893). Geology of the Sherani Hills: India Geol. Surv. Recds, vol. (26): pt. 3, 77-96.

Larsen, G., Chilingar, G.V. (1979). Introduction to diagenesis of sediments and rocks. Developments in Sedimentology, 25, 1-29.

Li, Z., Goldstein, R., &Franseen, E. (2017). Meteoric calcite cementation: diagenetic response to relative fall in sea-level and effect on porosity and permeability, Las Negras area, southeastern Spain. *Sedimentary Geology, 348*, 1-18. doi: 10.1016/j.sedgeo.2016.12.002.

Mahboubi, A., Moussavi-Harami, R., Carpenter, S., Aghaei, A., & Collins, L. (2010). Petrographical and geochemical evidences for paragenetic sequence interpretation of diagenesis in mixed siliciclastic–carbonate sediments: Mozduran Formation (Upper Jurassic), south of Agh-Darband, NE Iran. *Carbonates And Evaporites*, *25*(3), 231-246. doi: 10.1007/s13146-010-0028-z

Malkani, M. (2010). Updated startigraphy and Mineral Potential of sulaiman Basin, Pakistan. Sindh Univ..Res. Jour. (Sci. Ser.): Vol. 42 39-66.

Malkani, M. (2012). Revised lithostratigraphy of Sulaiman and Kirthar basins, Pakistan, in: Earth Sciences Pakistan 2012, Baragali Summer Campus, University of Peshawar, June 23–24, 2012, Pakistan: Abstract Volume and Program. J. Himalayan Earth Sci. 45(2), 72.

McLean, D. (1995). Provenance of reworked palynomorphs from the Greenmoor rock (Langsettian, late Carboniferous) near Sheffield, England. Review of Palaeobotany and Palynology, 89, 305-317.

Meissner, C. R., Hussain, M., Rashid, M.A., & Sethi, U. B. (1975). Geology of the Parachinar quadrangle Pakistan U.S.G.S. Prof. Paper, 76-f, 24p.

Meissner, C. R., Master. J. M., Rashid, M. A., & Hussain. M. (I968). Stratigraphy of the Kohat quadrangle, West Pakistan: *U.S. Geol. Surv., Proj. Rep. (IR) PK-20,* 86 p.

Métais, G., Welcomme, J., &Ducrocq, S. (2009). New lophiomerycid ruminants from the Oligocene of the Bugti Hills (Balochistan, Pakistan). *Journal Of Vertebrate Paleontology*, *29*(1), 231-241. doi: 10.1671/039.029.0115.

Najman, Y. (2005). The detrital record of orogenesis: A review of approaches and techniques used in the Himalayan sedimentary basins. Earth-Science Reviews, 74(1), 1–72. https://doi.org/10.1016/j.earscirev.2005.04.004.

Nelson, R. A. (2001). Geologic analysis of naturally fractured reservoirs. Gulf Professional Publishing, Second Edition, 323p.

Ni, X., Shen, A., Chen, Y., Guan, B., Yu, G., & Yan, W. et al. (2016). Comprehensive insight of the Cambrian carbonate platform types as well as margin segmentation characteristics' exploration in Tarim Basin, China. *Journal Of Natural Gas Geoscience*, *1*(1), 73-84. doi: 10.1016/j.jnggs.2016.04.004.

Payros, A., Pujalte, V., Tosquella, J., &Orue-Etxebarria, X. (2010). The Eocene storm-dominated foralgal ramp of the western Pyrenees (Urbasa–Andia Formation): An analogue of future shallow-marine carbonate systems. *Sedimentary Geology*, *228*(3-4), 184-204. doi: 10.1016/j.sedgeo.2010.04.010.

Philip H. Heckel. (1972). Possible Inorganic Origin for Stromatactis in Calcilutite Mounds in the Tully Limestone, Devonian of New York. *SEPM Journal Of Sedimentary Research*, *Vol. 42*. doi: 10.1306/74d72478-2b21-11d7-8648000102c1865d.

Pivnik, D., & Wells, N. (1996). The transition from Tethys to the Himalaya as recorded in northwest Pakistan. *Geological Society of America Bulletin*, *108*(10), 1295-1313. doi: 10.1130/0016-7606(1996)108<1295:ttfttt>2.3.co;2.

Powell, C. M. A. (1979). A speculative tectonic history of Pakistan and surroundings: Some constraints from Indian Ocean. In: Farah, A., De Jong, K.A. (Eds.), Geodynamics of Pakistan. Geological Survey of Pakistan, Quetta, 5-24.

PUGA-BERNABÉU, Á., MARTÍN, J., BRAGA, J., & SÁNCHEZ-ALMAZO, I. (2010). Downslope-migrating sandwaves and platform-margin clinoforms in a current-dominated, distally steepened temperate-carbonate ramp (Guadix Basin, Southern Spain). *Sedimentology*, *57*(2), 293-311. doi: 10.1111/j.1365-3091.2009.01079.x.

Racey, A. (1994). Biostratigraphy and palaeobiogeographic significance of Tertiary nummulitids (Foraminifera) from northern Oman. In: Simmons MD (ed) Micropalaeontology and hydrocarbon exploration in the Middle East. Chapman and Hall, London, pp 343–370.

Racey, A. (2001). A review of Eocene nummulite accumulations: structure, formation and reservoir potential. J Pet Geol 24:79–100. https://doi.org/10.1111/j.1747-5457.2001.tb00662.x.

Rasser, M., Scheibner, C., &Mutti, M. (2005). A paleoenvironmental standard section for Early Ilerdian tropical carbonate factories (Corbieres, France; Pyrenees, Spain). *Facies*, *51*(1-4), 218-232. doi: 10.1007/s10347-005-0070-9.

Raza, H.A., Ali, S.M., & Ahmed, R. (1989). Petroleum geology of Kirthar sub-basin and part of Kutch Basin. Pakistan Journal of Hydrocarbon Research, P.29-73.

Raza, S.M., Khan, S.H., Karim, T., & Ali, M. (2001). Stratigraphic Chart of Pakistan. Geological Survey of Pakistan, Quetta.

Rehman, S., Riaz, M., Ahmed, M., Ullah, M., & Kashif, M. (2017). Sedimentology of pirkoh formation exposed at Dholi and Rakhi Gaj, Central Sulaiman Range, Pakistan.

Reiss, Z., &Hottinger, L. (1984). The Gulf of Aqaba, ecological micropaleontology. Springer, New York, p 354.

Roddaz, M., Said, A., Guillot, S., Antoine, P., Montel, J., Martin, F., &Darrozes, J. (2011). Provenance of Cenozoic sedimentary rocks from the Sulaiman fold and thrust belt, Pakistan: implications for the palaeogeography of the Indus drainage system. *Journal Of The Geological Society*, *168*(2), 499-516. doi: 10.1144/0016-76492010-100.

Santantonio, M., Scrocca, D., &Lipparini, L. (2013). The Ombrina-Rospo Plateau (Apulian Platform): Evolution of a Carbonate Platform and its Margins during the Jurassic and Cretaceous. *Marine And Petroleum Geology*, *42*, 4-29. doi: 10.1016/j.marpetgeo.2012.11.008.

Sarwar, G., & DeJong KA. (1979). Arcs, oroclines, syntaxes: the curvature of mountain belts in Pakistan. Geodynamics of Pakistan, Geological Survey of Pakistan, Quetta p. 341-350.

Scholle, P. A., & Scholle D. S. (2003). A color guide to the petrography of carbonate rocks: grains, textures, porosity, diagenesis. AAPG Memoir 77(77):459.

Shafique, A.N**.** (2001). PhD Thesis: Spatial Biostratigraphy of NW Pakistan.

Shah, S.M.I. (1977). Stratigraphy of Pakistan. Geological Survey of Pakistan, Quetta, Memoir 12, p. 1-138.

Shah, S.M.I. (2002). Lithostratigraphic units of the Sulaiman and Kirthar provinces, Lower Indus Basin, Pakistan. GSP, Record (107): 63Pp.

Shah, S.M.I. (2009). Stratigraphy of Pakistan. Geological Survey of Pakistan, Memoir, 22, 271 pp.

SIBSON, R., MOORE, J., & RANKIN, A. (1975). Seismic pumping—a hydrothermal fluid transport mechanism. *Journal Of The Geological Society*, *131*(6), 653-659. doi: 10.1144/gsjgs.131.6.0653.

Sinclair, H., Sayer, Z., & Tucker, M. (1998). Carbonate sedimentation during early foreland basin subsidence: the Eocene succession of the French Alps. *Geological Society, London, Special Publications*, *149*(1), 205-227. doi: 10.1144/gsl.sp.1999.149.01.11.

Stoneley, R. (1974). Evolution of the continental margins bounding a former southern Tethys. Pages 889-903 in C. A. Burk and C. W. Drake, eds. *The Geology of Continental Margins.* Springer Verlag, New York.

Stuart, M. (1922). The Geology of the Taki Zam Valley, and the Kanigurarn-Makin area, Waziristan: Geol. Surv. India, Rec., 54 (I), 87-102.

Swart, P. (2015). The geochemistry of carbonate diagenesis: The past, present and future. *Sedimentology*, *62*(5), 1233-1304. doi: 10.1111/sed.12205.

Swei, G., & Tucker, M. (2011). Impact of diagenesis on reservoir quality in ramp carbonates: Gialo Formaton (Middle Eocene), Sirt Basin, Libya. *Journal Of Petroleum Geology*, *35*(1), 25-47. doi: 10.1111/j.1747-5457.2012.00517x.

Swennen, R., Ferketa, H., Benchilla, L., Roure, F., Ellam, R., & SUBTRAP team. (2003). Fluid flow and diagenesis in carbonate dominated ForelandFold and Thrust Belts: petrographic inferences from field studies of late-diagenetic fabrics from Albania, Belgium, Canada, Mexico and Pakistan. *Journal Of Geochemical Exploration*, *78-79*, 481-485. doi: 10.1016/s0375-6742(03)00064-5.

Tavakoli, V., Rahimpour-Bonab, H., &Esrafili-Dizaji, B. (2011). Diagenetic controlled reservoir quality of South Pars gas field, an integrated approach. *ComptesRendus Geoscience*, *343*(1), 55-71. doi: 10.1016/j.crte.2010.10.004

Tucker, M.E. and Wright, V.P. (1990). Carbonate sedimentology. Blackwells Scientifc Pulications, Oxford.

Vaziri-Moghaddam, H., Kimiagari, M. and Taheri, A., 2005. Depositional environment and sequence stratigraphy of the Oligo-Miocene Asmari Formation in SW Iran. *Facies*, 52(1), pp.41-51.

Vincent, B. (2001). Sédimentologie et géochimie de la diagenèse des carbonates: application au Malm de la bordure Est du Bassin de Paris. Dijon University, Dijon.

Vincent, B., Emmanuel, L., Houel, P. and Loreau, J., 2007. Geodynamic control on carbonate diagenesis: Petrographic and isotopic investigation of the Upper Jurassic formations of the Paris Basin (France). *Sedimentary Geology*, 197(3-4), pp.267-289.

Warraich, M., & Nishi, H. (2003). Eocene Planktic Foraminiferal Biostratigraphy of the Sulaiman Range, Indus Basin, Pakistan. *The Journal of Foraminiferal Research*, 33(3), pp.219-236.

Welcomme, J. and Ginsburg, L., 1997. Mise enévidence de l'Oligocène sur le territoire des Bugti (Balouchistan, Pakistan). *ComptesRendus de l'Académie des Sciences - Series IIA - Earth and Planetary Science*, 325(12), pp.999-1004.

WELCOMME, J., BENAMMI, M., CROCHET, J., MARIVAUX, L., MÉTAIS, G., ANTOINE, P. and BALOCH, I., 2001. Himalayan Forelands: palaeontological evidence for Oligocene detrital deposits in the Bugti Hills (Balochistan, Pakistan). *Geological Magazine*, 138(4), pp.397-405.

Williams, M.D. (1959). Stratigraphy of the Lower Indus Basin, West Pakistan. World Petroleum Cong., 5th, New York, Proc. Sec. (1): 277-394.

Wilson, M. (2000). A Colour Atlas of Carbonate Sediments and Rocks Under the Microscope; A.E. Adams, W.S. MacKenzie, Manson Publishing, 1998, 180 pp.; ISBN: 1 874545. *Marine And Petroleum Geology*, *17*(1), 123. doi: 10.1016/s0264-8172(99)00040-9.

WILSON, M. and VECSEI, A., 2005. The apparent paradox of abundant foramol facies in low latitudes: their environmental significance and effect on platform development. *Earth-Science Reviews*, 69(1-2), pp.133-168.

Wilson, P.D.J.L. (1975). The lower carboniferous Waulsortian facies. In: Wilson, J.L. (ed.) Carbonate Facies in Geologic History, pp. 148– 168. Springer, Berlin (1975).

Zhang, R., Jiang, D., Zhang, Z. and Yu, E., 2015. The impact of regional uplift of the Tibetan Plateau on the Asian monsoon climate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 417, pp.137-150.

PETROGRAPHIC AND DIAGENETIC INVESTIGATIONS OF HABIB RAHI LIMESTONE, SULAIMAN BASIN, NORTH WAZIRISTAN, KP PAKISTAN

by Fawad Ahmed

PETROGRAPHIC AND DIAGENETIC INVESTIGATIONS OF HABIB RAHI LIMESTONE, SULAIMAN BASIN, NORTH WAZIRISTAN, KP PAKISTAN

ORIGINALITY REPORT

16%	3%	11%	5%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Higher Education Commission Pakistan Student Paper	4%
2	Muhammad Ishaq, Irfan U. Jan, Muhammad Hanif, Muhammad Awais. "Microfacies and diagenetic studies of the early Eocene Sakesar Limestone, Potwar Plateau, Pakistan: approach of reservoir evaluation using outcrop analogue", Carbonates and Evaporites, 2018 Publication	3%
3	Umer Khitab, Muhammad Umar, Muhammad Jamil. "Microfacies, diagenesis and hydrocarbon potential of Eocene carbonate strata in Pakistan", Carbonates and Evaporites, 2020 Publication	2%
4	econ-environ-geol.org Internet Source	1%

5	Muhammad Rizwan, Muhammad Hanif, Nowrad Ali, Maqsood Ur Rehman. "Microfacies analysis and depositional environments of the Upper Cretaceous Fort Munro Formation in the Rakhi Nala Section, Sulaiman range, Pakistan", Carbonates and Evaporites, 2020 Publication	1 %
6	Bilal Wadood, Suleman Khan, Yiqun Liu, Hong Li, Ali Rahman. "Investigating the impact of diagenesis on reservoir quality of the Jurassic shallow shelfal carbonate deposits: Kala Chitta Range, North Pakistan", Geological Journal, 2020 Publication	1 %
7	nceg.upesh.edu.pk Internet Source	1 %
8	www.mediander.com Internet Source	<1 %
9	Mansoor Humayon. "STRUCTURAL INTERPRETATION OF THE EASTERN SULAIMAN FOLDBELT AND FOREDEEP, PAKISTAN", Tectonics, 1991 Publication	<1 %
10	Qorri, Ana. "Microfacies Analysis and Diagenetic Settings of Upper Cretaceous Shallow Water Carbonates from the Borizana	<1 %

Section (Kruja Zone, Albania)", Academic Journal of Interdisciplinary Studies, 2015.
Publication

11	Kalpana Deka Kalita, Hemlet Gogoi. "Microfacies types (MFT) and palaeoenvironment of the Umlatodoh carbonates in the Shillong Plateau of Meghalaya, NE India", Journal of the Geological Society of India, 2015 Publication	<1 %
12	A ALSHARHAN. "The Latest Part of the Zuni and Tejas Cycles in the Middle EastThe Cenozoic", Sedimentary Basins and Petroleum Geology of the Middle East, 1997 Publication	<1 %
13	Submitted to Science High School Student Paper	<1 %
14	Muhammad Kamran, Fabrizio Frontalini, Dangpeng Xi, Cesare Andrea Papazzoni et al. "Larger benthic foraminiferal response to the PETM in the Potwar Basin (Eastern Neotethys, Pakistan)", Palaeogeography, Palaeoclimatology, Palaeoecology, 2021 Publication	<1 %
15	Naveed Ahmad, Sikandar Khan, Abdullatif Al-Shuhail. "Seismic Data Interpretation and Petrophysical Analysis of Kabirwala Area Tola	<1 %

(01) Well, Central Indus Basin, Pakistan", Applied Sciences, 2021
Publication

16 www.upesh.edu.pk
Internet Source
<1%

17 Mukund Palat Rao, Edward R. Cook, Benjamin I. Cook, Jonathan G. Palmer et al. "Six Centuries of Upper Indus Basin Streamflow Variability and Its Climatic Drivers", Water Resources Research, 2018
Publication
<1%

18 sp.lyellcollection.org
Internet Source
<1%

19 Bilal Wadood, Mansoor Aziz, Junaid Ali, Nasar Khan, Jamal Wadood, Ahmad Khan, Muhammad Shafiq, Mohib Ullah. "Depositional, diagenetic, and sequence stratigraphic constrains on reservoir characterization: a case study of middle Jurassic Samana Suk Formation, western Salt Range, Pakistan", Journal of Sedimentary Environments, 2021
Publication
<1%

20 hdl.handle.net
Internet Source
<1%

21 researchbank.rmit.edu.au
Internet Source
<1%

22	Safiya M. Hassan. "Sequence Stratigraphy of the Lower Miocene Moghra Formation in the Qattara Depression, North Western Desert, Egypt", Springer Science and Business Media LLC, 2013 Publication	<1 %
23	Sajjad Ahmad, Suleman Khan, Bilal Wadood, Asad Naseer, Muhammad Noman, Jamal Wadood, Muhammad Muslim. "Late Cretaceous pelagic laminites at the northwestern margin of Indian plate, Pakistan: implications for basin bathymetry and ophiolite emplacement", Carbonates and Evaporites, 2021 Publication	<1 %
24	Tawadros, . "Paleozoic", Geology of North Africa, 2011. Publication	<1 %
25	Mina Khatibi Mehr, Mohammad H. Adabi. "Microfacies and geochemical evidence for original aragonite mineralogy of a foraminifera-dominated carbonate ramp system in the late Paleocene to Middle Eocene, Alborz basin, Iran", Carbonates and Evaporites, 2013 Publication	<1 %